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A study of the effects of ambient air, spray mist, and flood cooling on the wear-temperature relationship and the surface finish-temperature relationship for carbide cutting tools

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A STUDY OF THE EFFECTS OF AMBIENT AIR, SPRAY MIST, AND FLOOD COOLING ON THE WEAR-TEMPERATURE RELATIONSHIP AND THE SURFACE FINISH-TEMPERATURE RELATIONSHIP FOR CARBIDE CUTTING TOOLS

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ABSTRACT

The effect of temperature on tool wear in cutting metal with a carbide tool - with three distinct type coolants, ambient air, flow coolant, and spray mist - is the subject of this investigation.

Two different types of cut were used with the direction of fluid application being the same in all cases, that being directly above the tool-chip interface or directly on the tool as in cutting.

This investigation was made to determine which method of applying coolant was the most significant with respect to the resulting tool wear as a function of temperature measured at the interface by the tool-work thermocouple.

The results of the investigation show that the correlation between the temperature and the flank land wear is significant with respect to a positive type association. For all the speed ranges, the analysis shows that as the temperature increases while cutting the wear also increases. The average values of flank land wear were used to compare with the average values of temperature at the different speed ranges of 300, 400, 500, and the combined 600 and 700 surface feet per minute ranges varied from superiority of mist and flow conditions at 300 surface feet per minute; to superiority of dry cutting at 600 and 700 surface feet per minute.

The investigation also included the study of the surface finish only at the finishing speeds of 600 and 700 surface feet per minute. The results from the study indicated that the surface finish correlation with the temperature was not very significant, and that for this limited sample, further data should be investigated.

INTRODUCTION

The effect of the three types of coolants on flank land wear has been a subject of much investigation. The relationship of wear as a function of temperature has been very scantily investigated with respect to the usage of coolants. Sorensen and Kececioglu (1) state that in the lower speed range the fine mist is acting primarily as a lubricant between the tool flank and abrasive workpiece. This remark seems to be consistent with the findings of this investigation at the 300 surface feet per minute range. Likewise, the same authors reflect that "the improvement obtained from flood cooling at higher speeds, implies that heat transfer is the principal factor in reducing erosion at the tool-chip interface."

Shaw also concluded that at the lower speeds with the lower temperatures that boundary lubrication becomes more important. This once again seems consistant with the results of this study. Shaw states further that no temperature decreasing effect at cutting speeds above 400 surface feet per minute for a depth of cut of .0052 inch is present from the mist or flow type coolant. However, in this study there is a definite reduction in temperature and consequent wear for a depth cut of .030 inch.

The discussion of effect of depth of cut and feed rate is one that has been thoroughly examined. Downing shows that temperature increases with both increasing speeds and feed. Similarly, Trigger and Chao state that increasing feed in-

1. T.D.Kececioglu and A.S.Sorensen, "A Comparative Effect of Land and Crater Wear on Tool Life When Dry Cutting, Mist Cooling, and Flood Cooling," Tool and Manufacturing Engineer, February,1961,Page 4, Column 1.

creases the amount of heat produced, but with less of a heat increase than with speed. The additional chip material helps to remove some of the additional heat generated. The variable of feed is not present in this study since the feed is kept constant during the two types of cut, finish and roughting. The speed variable is certainly one of the major considerations. The range of speed is that which may be called the critical range. Since the flank land wear is adversely affected by increasing temperature, beyond a certain critical range, as pointed out by Sluhan, if tool temperature can be kept below this area, tool life can be prolonged.

Olberts states that certain speed ranges generate higher temperatures and higher wear while others do not. For instance, at the lower speed ranges up to around 300 surface feet per minute, increased temperature is not evidenced with increased wear. It is the purpose of this paper to attempt to pinpoint those speeds, which are the variables in this investigation, which show an increase in temperature or decrease by fluid action with an increase in wear or consequent decrease in wear. If the cutting fluid can decrease the wear by decreasing the temperature, a measurable amount of savings can be obtained by realizing the extra or prolonged tool life evidenced in utilizing carbide tools in metal cutting. The problem of reaching the cutting edge of the tool is a function of many variables. In this study, the variable of speed was used to determine the effectiveness of fluid in reaching the cutting edge and carrying away the heat.

It is well known that 99% of the energy produced in cutting is transferred into heat and that heat is the enemy of tools because of the red hardness limitation, reducing their useful cutting life.

The results of Sorensen and Kececioglu show that at 600 sfpm mist cooling reduces tool life by 6 per cent over dry cutting, whereas flood cooling increases it by 12 per cent over dry cutting. These results are consistent with the findings of this investigation in that flow cooling shows a considerable reduction in temperature over dry cutting and a reduction in flank land wear also where as mist cooling does not reduce the temperature as significantly as the flood coolant and has more flank wear than the dry cutting. Once again the matter of carrying away the heat seems to be very significant in affecting the resulting wear relationship.

The correlation of flank land wear and temperature of the interface produced by utilization of coolants has not been investigated and reported in any published findings. Sorensen and Kececioglu did investigate the effect of the three type coolants on flank land wear and crater wear using carbide tools, but no mention of any correlation with interface temperatures is discussed in this paper. If the well known assertion that 99% of the work in cutting is transferred into heat can be significant in solving or alleviating the problem of tool wear caused by the heat. Heat certainly affects the tool in that it tends to soften the tool and reduce the effectiveness of the tool in cutting.

Although this investigation was done on only one type carbide tool and one specific steel workpiece, it should suggest the possibility of future ascertainment of temperature-wear relationship with other type carbides on various work materials.

The effectiveness of the coolants should also prevent unnecessary expenses in purchasing or utilizing coolants in those speed ranges where dry cutting may be as good or even better than a coolant which becomes almost totally ineffective.

Similarly, the investigation seeks to statistically prove the superiority or inferiority of the three type methods of applying a fluid. Once again unnecessary expenditure can be prevented for a sophisticated or costly mist system or flood system, if the range of cutting is out of the critical range of effectiveness.

Other areas that should be investigated, such as different coolant compositions and direction of application, will be mentioned in the section concerning future study in this problem area.

The direction of application of fluid in this study, that of directly on top of the chip tool interface, was selected because of its common usage in industry and ease of operator handling. There are other theories that recommend application along the clearance face of the tool and from the bottom of the tool in a "capillary" type of action.

Finally, the rate of flow of the flood type of application is another area which the author deems worthy of consideration. For this study, a steady stream of flow of approximately 1.5 gallons per minute was used. The effect of this variable was not considered since the stream flow was kept at a constant condition.

OBJECT AND SCOPE OF THE INVESTIGATION

The object of this investigation was to determine the effects of three type coolants, ambient air, spray mist, and flood cooling upon the tool chip-interface temperature and its consequent relationship with flank land wear.

Since the primary purpose of any coolant is ~~to~~ carry away the heat from the cutting zone, of which 99% of the work done in cutting is transferred into heat, this investigation sought those zones in which the reduction in heat at the interface corresponded to a subsequent reduction in flank land wear.

From other studies, it was realized that at certain speed ranges, which were the variables in this study, the cooling action of the three type coolants was subject to different phenomena. As an example, in the low speed ranges of up to 300 surface feet per minute, the phenomenon of "boundary lubrication," as mentioned by Sluhan and Shaw, overruled the wear results much more than that of the "cooling action" of the three type coolants. "The ability of a fluid to form a low shear strength material prevents or drastically reduces the minute weldments which would otherwise form between the chip and tool, and thus reduces friction, consequently preventing the built-up-edge from forming." The theory is that because of the extremely high pressures involved, an ordinary "hydrodynamic lubrication" effect cannot exist.[2]

2. Clyde Sluhan, "Cutting Fluids," A.S.T.M.E. Technical Paper No. 399, 63 (1963), page 5

The investigation purposely selected the low speed range of 300 sfpm to prove or validate this "boundary lubrication" phenomenon. It was decided that be investigating both the extreme points of the low speed ranges and the high speeds, 700 sfpm, that a definite range could be attained wherein the validity of the three type coolants might be illustrated.

The high speed range limit was set at 700 sfpm in order to investigate the phenomenon of both too much heat being generated and insufficient time for the fluid to penetrate the cutting zone or the chip tool interface. At the high speeds, it is hypothesized that the heat generated is increased and also the rate of reaction of the coolant is increased. "This is desirable unless too high a heat is developed and the chemical compounds fromed are decomposed and their effect lost. There is less time for the chemical reaction to take place on the chip because of increased speed of chip travel."[3]

If the above mentioned phenomenon takes place at the higher speeds, it should set an upper limit to the usefulness of the three type coolants studied in this investigation. The 700 and 600 surface feet per minute ranges were selected to validate these considerations.

The zone established by the upper and lower limits of speed was intended to illustrate the effectiveness of collants in performing the function of carrying away the heat, and more significant to this study, the concrete relationship

3. Clyde Sluhan, "The Effective Utilization of Cutting Fluids to Improve Metal Removal Rates," A.S.T.M.E. Technical Paper SP 63-188, (1963), Page 4.

of reduction in temperature to reduction in flank land wear.

The zone of effectiveness was also considered with respect to what particular type method of applying coolant, mist, flood, or air illustrated the best relationship of reduction in temperature to reduction in flank land wear.

Much has been written concerning the relative merits of both mist, air, and flood cooling, especially with respect to reduction in tool wear or increase in tool life. This investigation sought to classify those areas or speed ranges for a typical roughing or finishing cut in which one method significantly proved itself better than the other.

The author would like to point out that the scope of the investigation is such that only water based coolants are used and analyzed. There are many other types of cutting fluids which could be analyzed, but it is only the water based coolant that was selected because of the heat removal qualities of water.

Before any actual cutting was undertaken preliminary characteristics of cutting were studied on the machinability computer, in order to ascertain the approximate tool wear at certain time intervals for the two types of cuts and the general distinction between the dry and the wet type cutting. Knowing the cutting conditions, the work material, tool material and the necessary physical properties of both tool and work, certain times were established for the different types of cut with regard to tool life, primarily based upon the standard of .030 inch flank land wear as tool failure. The chart illustrating the results of the machinability computer is found in the appendix B.

By utilizing the results of the machinability computer, it allowed the author to decide on the time intervals of 0 to 1 minute, 1 to 2 minutes, and 2 to 2 minutes of cutting time. These time intervals were utilized in order to obtain significant plots of the three type coolants at the various speed ranges. Each speed was investigated for three different iterations and an average result obtained for the three type of coolants applied during the cutting. The tool was allowed to run for one minute, after which it was taken out of the holder and its flank land wear measured along with the equilibrium temperature of that period of time. The tool was then replaced in the tool holder and run for another minute. The same procedure was enacted as after the first minute, and then the tool was allowed to run another minute. This procedure allowed for each edge a total time of three minutes of actual cutting.

The objective of the time differential was to obtain the curvilinear relationship of the three coolants used in the study.

Another section of the investigation is to correlate the surface finish obtained during the finishing cuts at 600 and 700 surface feet per minute. Once again the aim was to determine whether the reduction in the temperature caused by the coolant subsequently caused a better surface finish, similar to that of a lower tool flank land wear.

The speeds of 600 and 700 surface feet per minute were chosen because at these speeds, it is normal industrial practice to perform a finishing type of cut. In this case the feed rate is a light .010 inch per revolution and the depth of cut is .030 inch. The investigation of surface finish concerned itself heavily with the presence of the built-up-edge. "At high temperatures, there is a tendency for the chip to weld to the tool because of the increased chemical reactions. The built-up-edge is an unstable condition that is formed and released continually, part of it passing off on the chip surface adjacent to the tool face, and part passing by the flank or relief face of the tool."[4] This phenomena can cause a rough surface to the chip and to the workpiece being cut. One of the aims of the investigation was to try to control this built-up-edge in order to obtain a better surface finish. If the temperature could be reduced by the coolant, then it was hypothesized that the finish obtained would be less severely affected by a large built-up-edge.

However, as Trigger points out, by increasing speeds there is less time for the built-up-edge to occur. Therefore at speeds of 600 and 700 surface feet per minute, it was purposeful to see whether a built-up-edge really appeared

4. Sluhan, Op. Cit., page 2.

and caused poorer surface finishes or whether the sought after reduction in temperature wear also contributed to better surface finishes.

Another purpose of the investigation that coincided with surface finish was that of analyzing the effect of the coolant in so far as its wetting and lubricating properties. If the coolant did seem to wet and lubricate the cutting zone, there should have been good finishes evidenced and similarly if the temperature of the tool was reduced the tool life also would be lengthened causing less pressure in the cutting zone and helping to reduce the advent of a large and undesirable built-up-edge.

APPARATUS

The tool material used in this experiment was K-21 grade carbide of the style SN6-434. This is a square insert made by Kennametal whose dimensions are shown in the appendix B. The tool was chosen because it is highly resistant to thermal shock and is used for moderate to heavy loads on roughing cuts.

The composition of the tool is as follows: CO - 9.3%, Ta - 8.0%, Ti - 5.5%, Ni - 3.0%, W - 74.2. It has a hardness of Rockwell "A" of 91.0 and a density of 12.3.

Since the tools were inserts, there was no need for grinding or regrinding in the experiment. This factor may be of consideration if the carbide was not an insert and would definitely present a consideration in economics of machining.

The work material that was used was 4145 steel, HR, with a Brinnell hardness of 280. The work material was chosen because of its significance in hardness in allowing readings of temperatures for both the finish and rough type of cuts.

The cutting conditions were of a roughing type: feed rate equal to .020 inch per revolution and depth of cut equal to .100 inch for the speeds of 300, 400, and 500 surface feet per minute. The finish type cut had a feed rate of .010 inch per revolution with a depth of cut of .030 inch for speeds of 600 and 700 surface feet per minute.

The cutting was done with a Kendex toolholder which allowed for a rake angle of minus 5 degrees, relief angles of 5 degrees, and an end cutting edge angle of 15 degrees. The tool had a nose radious of one-sixteenth of an inch. The tool holder was placed in a conventional tool post on the LeBlond engine lathe utilizing the proper center height. The lathe had a speed range of 16 to 2000 revolutions per minute. No surface speed indicator vari-dyne unit was available for this investigation, consequently the surface feet readings had to be adjusted utilizing stepped diameters of the workpiece.

Tool wear (flank land wear) was measured by the use of the tool maker's microscope. No crater wear was measured since it was not part of the scope of investigation. The surface finish readings were taken by using the Brush Surfindicator. These results of surface finish were analyzed only for the finishing cuts of 600 and 700 surface feet per minute. An arithmetic average scale was set on the surfindicator for all readings of surface finish.

TOOL WORK THERMOCOUPLE

The means used for obtaining temperature readings in this experiment was the tool work thermocouple. "According to thermoelectric theory, if two dissimilar metals are joined to form a closed loop and the two resulting junctions are maintained at temperatures T_1 and T_2 respectively, an emf will be generated which is proportional to the quantity T_2-T_1." (5) The tool work thermocouple is based on this theory and the two dissimilar metals utilized in this investigation are the steel work piece and the carbide tool insert. Some of the important features of the tool work thermocouple which should be mentioned are that the emf generated is independent of temperature gradients along the wire constituting the circuit, but only depends upon the difference between the hot and cold junctions T_2-T_1. The emf generated is also independent of the size or resistance of the conductors. Also the emf generated is not affected by the introduction of a third metal if a junction of the two dissimilar metals is at a uniform temperature. The tool work thermocouple measures the average temperature at the chip tool interface.

A chip of the workpiece was used as a brush contact riding on the end of the rotating workpiece to provide one of the junctions of the thermocouple and the other junction was the carbide tool insert cutting the workpiece. The carbide

5. Shaw, Pigott, and Richardson, "The Effect of Cutting Fluid Upon Chip-Tool Interface Temperature," Transactions of the A.S.M. E., 73, (1951), page 45.

insert was insulated by using a ceramic seat in the tool holder on which the insert was placed and by using .010 inch thick plastic strips in the tool holder seat on the sides of the insert in the tool holder. A chip breaker was used of the same material as the carbide tool insert and placed upon the insert. A piece of ceramic was then placed upon the chip breaker to complete the insulation, clamped down tightly by the tool holder clamp. The specifications of the tool holder are illustrated in the Appendix B. The reason for this type holder is the insert clamp which allows for the use of the ceramic insulation. The need for insulation with the tool work thermocouple is imperative in order to obtain accurate temperature readings or emf readings. Essentially then, as stated by Shaw, the tool work contact area serves as the hot junction and the emf generated is proportional to its temperature.

A necessary step in using the tool work thermocouple is the calibration of the thermocouple. This step was accomplished by joining a long chip generated from the workpiece and a carbide calibration rod of the same material as the carbide tool insert. The two metals were then placed into a furnace touching one end of a chromel-alumel reference thermocouple. The chip and the carbide rod had leads attached to the end of each leading into potentiometer. The reference thermocouple also had leads attached to another potentiometer. The furnace was set up to 1800°F and readings were taken from 1800°F in 50° intervals. The reference thermocouple had known millivolt readings for the various temperature intervals, and corresponding millivolt readings were then obtained for the tool work thermocouple. These values were then used to ascertain the temperature readings from the millivolt output on the temperature recorder. A calibration curve was drawn as a result of readings obtained with the reference thermocouple. A peculiarity was encountered at a temperature of 1300°F, this being a definite change in the slope of the calibration curve, probably due to the allotropic transformation in the steel. A similar phenomena was evidenced in calibration by Trigger in his report of interface temperatures. After this point is reached, the remainder of the califbration curve was very linear in appearance. Trigger's method of utilizing the original slope of the calibration curve from the low point upward, beyond the 1300°F transformation point, was used. The reason for this is that by the time this mv reading is obtained, the cutting speeds were such that there was not sufficient time for the allotropic transformation to occur while the chip was in contact with the tool.

A Honeywell x-y recorder was used to determine the millivolt readings from the tool work thermocouple. Before obtaining readings from the recorder, a warm-up period of thirty minutes was allowed to insure proper results. The recorder was

The recorder was properly calibrated and checked by using a potentiometer to insure the millivolt output was correct.

The tool work thermocouple procedure consisted ~~of~~ touching the tool, which had been connected to one lead of the thermocouple plug to the workpiece in conjunction with the brush lead, and adjusting the recorder reading to zero with the zero adjustment know set on 5, the proper calibration number. When the tool was removed from the workpiece the recorder then went to full scale indicating that the circuit was not complete as desired. The output dial was set on the number 4 scale, which meant that the readings from 0 to 100 represented 20 millivolts. This dial setting was sufficient for the readings that were obtained during the investigation.

The thermocouple leads were of a copper variety with ceramic insulation to prevent any shorting during cutting or contact with any foreign substance, such as the tool post, coolant, chip, etc. The leads were checked periodically by the use of a standard ohmmeter to insure continuity in the circuit.

This apparatus was different from others such as that of Trigger in that no carbide strip was inserted into the tool holder. The use of the plastic inserts and ceramic insulation of both wire and tool allowed for ready removal of tools and calibration during the entire experiment. The chip that was used as the brush was dabbed with silicone grease to prevent any unnecessary chattering or uneveness as it rode along the end of the workpiece as the work was turning. Some discussion is made concerning the use of a chip since it has changed properties due to the action of cutting. However, the temperature measured is that of the cut chip whether it be strain hardened or not, and, therefore, validates the usage of the chip as the brush or second part of the tool work thermocouple.

In calibration the cold junction of the tool work thermocouple, i.e., the two leads coming from the carbide rod and the long chip generated from the workpiece, were kept at an ambient temperature or as close to room temperature as possible. It was decided that by doing this, the need for ice cooling or any other means would be eradicated both in calibration and in actual cutting in the laboratory. Since the temperature at the cold junction is of extreme importance in measurement of the average interface temperature, i.e., T_2-T_1, the ambient temperature of both calibration and actual cutting were consistent and allowed for proper results of the interface temperatures.

The coolant that was used for this study was Trim Regular, supplied by the Master Chemical Corporation. The ratio used for the flood cooling was two (2) gallons of Trim to 40 gallons of water or a 20:1 water ratio. The coolant was chosen because of its excellent wetting characteristics, something essential to this type of investigation. The mist solution was a 40:1 ratio of water to Trim regular, and it was dispensed by the conventional type mist setup, in which the fluid was mixed with compressed air and discharged through two nozzles in a finely atomized spray. The mist was applied directly above the tool at a distance of two inches from the chip-tool interface. The nozzles were rigidly clamped to the tool post for complete support and continuous, steady spray upon the workpiece.

RESULTS OF TESTS

To analyze the data generated in this investigation certain statistical methods were selected in specific regard to correlation of the temperature and wear, differentiation among the three type coolants, and significance of the variables inherent to the investigation.

A multiple linear regression analysis was performed, utilizing the G.E. 225 Computer, in order to investigate the correlation or degree of association between the selected variables. Through the regression technique, a correlation coefficient was obtained indicating the amount to denote the correlation coefficient. Values of 0.0 to 1.0, a completely random relation, and for 1.0, a perfect association between the variables.

The first analysis that was performed with the multiple regression technique was the establishment of a relationship for the wear variable as a function of the temperature and the speed. The following mathematical expression was used:

X_1 = a plus b)X_2) plus c (X_3)

X_1 = dependent variable - wear

a = constant term

b = regression coefficient

c = regression coefficient

X_2 = independent variable - temperature

X_3 = independent variable - speed

A curve was obtained from the values of this mathematic expression whose fit is forced through the mean. Also the coefficients of correlation are obtained for the relationship of temperature versus wear, wear versus speed, and temperature versus speed. The most important relationship is that of wear versus temperature for this study.

The following results for the five speeds, 300, 400, 500, 600 and 700, are:

Regression equation

$X_1 = -.708$ plus $.194\ X_2 - .138\ X_3$

r (correlation coefficient) X_1 vs. $X_2 = .241$

The average values of wear were used for the corresponding average temperature readings at the various speeds noted above.

The fit had an "f" value confidence level of 1, which means that the temperature effect on the wear is significant from a 90% to 95% confidence level. Another extremely important result is that with the Degrees of Freedom of 45, this correlation coefficient of .241 is as follows:

$r = .243$ value or 90% probability of correlation at 45 DOF.

$r = .243 = .241 \therefore r = .241$ has a probability of 90% of correlation with only a 10% chance of being wrong.

The multiple regression analysis was further utilized to differentiate between speeds, and also for single speed values in order to establish strength to the temperature versus wear relationship.

The speeds of 500, 600, and 700 were combined and a regression expression was obtained for these speeds. Once again the same variables are used as in the analysis for all the speeds.

The regression expression is as follows:

$$(X_1) = 50.00 \text{ plus } 1.32(X_3) -9.18(X_2).$$

This analysis had 27 observations or degrees of freedom. The correlation coefficient for the wear versus temperature relationship was .22803. This value turns out to be not significant, in that it is less than the 90% probability value. The "f" value or test of the level also shows the confidence level to be 0, which means that there is less than 90% confidence that the variable is significant.

The "r" value for the wear speed relationship is interesting. This value is -.76625, which means that it is very significant with a confidence level of 99%. The negative correlation means that as the speed increases, the wear decreases, and vice versa. This relationship is reasonable from the data since in the experiment the higher speeds of 600 and 700 are the finishing cuts.

The speeds of 400, 500, and 600 were used for another regression analysis. Once again the temperature versus wear relationship was investigated. The coefficient of correlation for wear versus temperature was .188016, which was not significant with its 27 degrees of freedom. The analysis showed that there was less than 90% confidence that the temperature variable was significant ("f" test.)

The wear versus speed correlation coefficient was -.342, which at 27 degrees of freedom is indicative of correlation at 90% but less than 95% probability. The "f" value shows that the confidence level is less than 90% that the variable of speed is significant.

The negative correlation of the speed variable is partly caused by the dry condition results, which peak at the two minute time interval.

The correlation analysis was then continued to establish those speeds or speed ranges which correlated the best, and the coolant conditions at the speeds.

The following are the results for the speeds of 600 and 700:

Regression expression - $(X_1) = -22.75$ plus $.00978\ X_2$ plus $.01525\ X_3$

Temperature versus Wear - r - value - Dry is .726

The correlation is established at between 95% and 98%. There are 6 degrees of freedom.

The "f" value has a 95% to 99% confidence level that the variable is significant.

The speed-wear relationship is not significant for this range.

At speeds of 400 and 500 for the Dry condition, the following results are:

"r" - Wear versus Temperature - -.397

For 6 degrees of freedom, the correlation is less than 90% probable.

The "f" value has less than a 90% confidence level that the temperature variable is significant.

"r" - Wear versus Speed - .651

For 6 degrees of freedom there is a 90% probability of correlation.

The "f" value has less than 90% confidence that the speed variable is signficant.

Once again the results of dry cutting can be studied to investigate the negative correlation.

Results for speeds of 400 and 500 of flow cutting are:

Regression expression $(X_1) = 36.82$ plus .1145(X_2)-3.977(X_3)

"r" - Wear versus Temperature = -.90669

The correlation is established at 99% probability and the "f" test shows less than 90% confidence level that the variable is significant. There were 6 degrees of freedom.

"r" - Wear versus Speed = .928

The correlation is established at 99% probability, but the "f" test shows less than 90% confidence that the variable of speed is significant.

Results for flow cutting at speeds of 600 and 700:

Regression expression - $(X_1) = -39.40$ plus $2.334(X_2)$ plus $1.017(X_3)$

"r" - Wear versus Temperature - .80336

The correlation is established at 98%, but the "f" test shows less than 90% confidence level that the variable of temperature is significant. There were 6 degrees of freedom.

"r" - Wear versus Speed - .7033

The correlation is established at 90% to 95% probability, but the "f" test shows less than 90% confidence that the variable is significant.

Results for Mist cutting at speeds of 400 and 500:

Regression expression - $X_1 = -225.22$ plus $.14207(X_2)$ plus $.00413(X_3)$

"r" - Wear versus Temperature = .92605

The correlation is established at 99.9% probability but the "f" test value shows less than 90% confidence level that the variable is significant. There were 6 degrees of freedom.

"r" - Wear versus Speed - .8705

The correlation is established at 99% probability. The "f" test value shows that there is less than 90% confidence that the variable of speed is significant.

Results for Mist Cutting at speeds of 600 and 700:

Regression expression - $(X_1) = -27.5$ plus $.016(X_2)$ plus $.027(X_3)$

"r" - Wear versus Temperature = .7667

The correlation is established with between 95% to 98% probability. There were 6 degrees of freedom. The "f" value indicated that there was 95% to 99% confidence that the variable of temperature was significant.

"r" - Wear versus Speed - .4165

For 6 degrees of freedom - not correlated.

"f" value indicated that there was 95% to 99% confidence that the variable of speed was significant.

The next test that was used in the investigation was the analysis of variance. In conjunction with this analysis of variance the "F" test for variances was used. The "F" test provides a method for determining whether the ratio or two variances is larger than might be expected by chance if they had been drawn from the same population. The "F" values are used in this experiment to test whether one variance estimate is larger than another, and whether the two variances are significantly different.

The "f" test was performed for the complete speed range

300 to 700 with wear being the dependent variable. Also the "f" test was performed with temperature being the dependent variable.

The purpose of the "f" test of the analysis of variance was to establish the significance of the variables speed, time, and coolant upon the two selected dependent variables of temperature and flank land wear. This method was a means of pinpointing the effect of the coolant at the various speeds and the significance level thereof.

The following is a table for the "f" test - Wear (dependent variable), Speed, Time, Coolant - independent variables.

Note: DOF = degrees of freedom

		"f" Value
A - Speed	4 DOF	$\frac{1248.9}{5.29} = 234$ Very significant with .001 probability of being in error.
B - Time	2 DOF	$\frac{260.5}{5.29} = 50$ Very significant with .01 probability of being in error.
C - Coolant	2 DOF	$\frac{299.37}{5.29} = 58$ Very significant with .01 probability of being in error.

		"f" Value
A-C-Speed-Coolant	8 DOF	$\frac{13.44}{5.29} = 2.54$
		Significant with less than .05 probability of being in error, but greater than .01.
Within	45 DOF	(5.29)

The values of the variables are compared with the variation within the units in order to determine whether there is a significant difference between variance estimates.

"f" test for temperature (dependent variable) for speeds 300 - 700.

	DOF	"f" Value	
A - Speed	4	$\frac{6.98}{1.97} = 4.18$	99% significant
B - Time	2	$\frac{1.61}{1.67} = .98$	Not significant
C - Coolant	2	$\frac{6.31}{1.61} = 3.79$	95% significant
A-C-Speed Coolant	8	$\frac{1.01}{1.67} = .605$	Not significant
Within	45	(1.97)	

The A-C-Speed-Coolant interaction was important in order to ascertain its effect upon both temperature and wear, since these two variables were the ones that changed the most and controlled the experiment.

"F" Test - Wear (dependent variable) Speeds - 600, 700.

	DOF	"F" Value	
A - Speed	1	$\frac{41.17}{1.86} = 22.2$	99% Significant
B - Time	2	$\frac{12.34}{1.86} = 6.84$	99% Significant
C - Coolant	2	$\frac{41.88}{1.86} = 22.5$	99% Significant
AC-Speed-Coolant	2	$\frac{3.71}{1.86} = 2.0$	Not Significant

.ol Probability of a larger value of "F" = 8.28

"F" Test - Wear (dependent variable) Speed = 500.

	DOF	"F" Value	
B - Time	2	$\frac{77.93}{16.46} = 4.74$	95% Significant
C - Coolant	2	$\frac{164.63}{16.46} = 10.2$	99% Significant
BC-Time-Coolant		$\frac{6.22}{16.42} = .38$	Not Significant

"F" Test - Wear (dependent variable) Speed = 400

	DOF	"F" Value	
B - Time	2	$\frac{498.8}{7.07} = 71.3$	99% Significant
C - Coolant	2	$\frac{107.82}{7.07} = 15.3$	99% Significant
BC-Time-Coolant	4	$\frac{4.47}{7.07} = .62$	Not Significant

"F" Test - Temperature (dependent variable) Speed = 400

	DOF	"F" Value	
B - Time	2	$\frac{16.09}{2.61} = 6.15$	99% Significant
C - Coolant	2	$\frac{4.119}{2.618} = 1.58$	Not Significant
BC-Time-Coolant	4	$\frac{4.66}{2.61} = 1.79$	Not Significant
Within	18	(2.61)	

.01 value of larger "F" = 6.01

.05 value of larger "F" = 3.55

"F" Test - Temperature (dependent variable) Speed = 500

	DOF	"F" Value	
B - Time	2	$\frac{.432}{5.70} = .08$	Not Significant
C - Coolant	2	$\frac{1.23}{5.70} = .214$	Not Significant
BC-Time-Coolant	4	$\frac{1.24}{5.77} = .214$	Not Significant

.01 value of larger "F" = 6.01

.05 value of larger "F" = 3.55

"F" Test - Temperature (dependent variable) Speed = 600, 700

	DOF	"F" Value	
A - Speed	1	$\frac{.298}{2.41} = .1$	Not Significant
B - Time	2	$\frac{3.93}{2.41} = 1.64$	Not Significant
C - Coolant	2	$\frac{7.35}{2.41} = 3.04$	90% Significant
AC-Speed-Coolant	2	$\frac{.288}{2.41} = .12$	Not Significant
Within	18	(2.41)	

.05 value of larger "F" = 3.55

.10 value of larger "F" = 2.097

These "F" tests were not designed to establish which type coolant is the best or to bring out correlation between variables, but solely to point out the significant difference between the units when compared with the variation within the units. The analysis of variance shows whether the factors or variables make a contribution to the variance of the measurements. The manner in which the variance of the measurement is related to the variance of the variables was a part of the regression and correlation method. The analysis of variance is basically a testing of a hypothesis that the variances are equal, and accepting the probability risks of being in error once the hypothesis is accepted or rejected.

The final test was used as a part of the statistical analysis was the "t" test. This test analyzed the difference between two means. In the experiment it was used to test for a significant difference between the three types of coolants with the dry condition being the model of comparison. This test gave the significant difference between coolants, and indicated which type or method seemed the best as far as the flank land wear variable was concerned.

"t" test - $t = \frac{(X_1 - X_2)}{\bar{S}(X)\sqrt{2/K}}$

K = No. of observations

$\bar{S}$ (X) = Standard deviation

The X values were calculated for the wear values for all three minutes of the various speed ranges. Each type or method of coolant had a specific X value or mean.

"t" test - Speed = 400

Dry $X_1 = 21.3$ Flow $X_2 = 6.5$ Mist $X_3 = 12.6$

$\bar{S}(X) = \sqrt{7.07} = 2.65$ K = 27

1. Dry versus Flow $t = \frac{(21.3 - 6.5)}{(2.65\,(\sqrt{2/27})} = \frac{14.8}{.72} = 20.6$

2. Dry versus Mist $t = \frac{(21.3 - 12.6)}{.72} = 12.1$

3. Mist versus Flow $t = \frac{(12.6 - 6.5)}{.72} = 8.5$

Two-sided test -

Degrees of freedom = N_1 plus $N_2 - 2 = 18-2 = 16$

The results of the "t" test show that both the Mist and Flow conditions are significantly different from the dry condition. Also the flow condition when compared to the mist condition shows significant difference at the 99% confidence level. Therefore, at the speed of 400 surface feet per minute, we conclude that flow coolant is superior.

"t" Test - Speed = 500 $\quad$ K = 18

Dry $X_1 = 28.5$ $\quad$ Flow $X_2 = 21.9$ $\quad$ Mist $X_3 = 27.6$

$\overline{S}(X)\sqrt{16.416} = 4.04$

1. Dry versus Flow $\quad$ $"t" = \dfrac{(28.5 - 21.9)}{4.04\sqrt{2/18}} = \dfrac{6.6}{1.35} = 4.9$

2. Dry versus Mist $\quad$ $"t" = \dfrac{(28.5 - 27.6)}{1.35} = \dfrac{.9}{1.35} = .67$

3. Mist versus Flow $\quad$ $"t" = \dfrac{(27.6 - 21.9)}{1.35} = \dfrac{5.7}{1.34} = 4.22$

Two-sided Test - Degrees of Freedom = 6 plus 6 - 2 = 10

The results of the "t" test show that the Flow condition differs significantly from both the Dry and Mist conditions at a 99% confidence level. The Mist and Dry conditions do not differ significantly. Therefore, we can conclude for a speed of 500 surface feet per minute that flow coolant is superior for wear.

"t" test - Speeds = 600 and 700 $\quad$ K = 36

Dry $X_1 = 5.19$ $\quad$ Flow $X_2 = 6.10$ $\quad$ Mist $X_3 = 7.20$

$\bar{S}(X) = \sqrt{1.86} = 1.36$

1. Dry versus Flow $\quad "t" = \dfrac{(5.19 - 6.10}{1.36\sqrt{2/36}} = \dfrac{.91}{.32} = 2.84$

2. Dry versus Mist $\quad "t" = \dfrac{(5.19 - 7.20)}{.32} = \dfrac{2.01}{.32} = 6.3$

3. Mist versus Flow $\quad "t" = \dfrac{(7.20 - 6.10}{.32} = \dfrac{1.10}{.32} = 3.44$

Two-sided Test - Degrees of Freedom - 12 plus 12 - 2 = 22

The results of the "t" test show that the Dry condition differs significantly from both the Mist condition and the Flow condition. The flow condition differs from the Mist significantly at a 99% confidence level, which is the same confidence level for the Dry. We can conclude that the Dry condition is therefore superior at speeds of 600 and 700 surface feet per minute for wear results.

"t" Test - Speed = 300 $\qquad$ K = 18

Dry $X_1 = 14.4$ $\qquad$ Flow $X_2 = 6.6$ $\qquad$ Mist $X_3 = 5.9$

$\bar{S}(X) = \sqrt{2.01} = 1.41$

1. Dry versus Flow $\quad "t" = \dfrac{(14.4 - 6.6)}{1.41\sqrt{2/18}} = \dfrac{7.8}{.47} = 16.6$

2. Dry versus Mist $\quad "t" \dfrac{(14.4 - 5.9)}{.47} = \dfrac{8.5}{.47} = 18.0$

3. Mist versus Dry $\quad "t" = \dfrac{(6.6 - 5.9)}{.47} = \dfrac{.7}{.47} = 1.48$

Two-sided Test - Degrees of freedom = 6 plus 6 - 2 = 10

The results of the "t" tests show that both the Mist and Flow conditions differ significantly from the Dry condition at a 99.9% confidence level. The Mist and Flow do not differ significantly when compared to each other. We can conclude, therefore, that both Mist and Flow are superior to Dry in reduction of flank land wear, but neither is significantly different from each other.

The correlation analysis was extended to the dependent variable of surface finish for speeds of 600 and 700 surface feet per minute. The following results were obtained: "r" - surface finish vs. temperature = .18267.

At 18 degrees of freedom, this value for the coefficient showed no significant correlation as did the "F" test value which indicated less than 90% confidence that the variable of temperature or speed is significant.

The analysis of variance and "F" test technique showed that the coolants had a low signifiance of 90% when compared with the variation within upon the surface finish, as did the interaction of the speed and coolant upon the surface finish.

<u>"F" Test Results</u>

	DOF	"F" Value	
A - Speed	4	$\frac{23.36}{257.6} = .09$	Not significant
B - Time	2	$\frac{589.0}{257.6} = 2.2$	Not Significant

	DOF	"F" Value	
C - Coolant	2	$\frac{861.58}{257.6} = 3.34$	Low Significance at 90%
AC-Speed-Coolant	2	$\frac{868.36}{257.6} = 3.38$	Low Significance at 90%

Since the correlation analysis was not significant, and the effect of the coolant and speed-coolant interaction low at 90%, the analysis was not extended further to differentiate between the three types of coolants.

CONCLUSIONS

The investigation of the temperature versus wear relationship and the temperature versus surface finish relationship resulted in a mixture of strongly significant results and possible suggestions for those results not statistically significant. The results strongly suggested consideration of previous known phenomena in metal cutting and provided an impetus for further analysis of the effects of coolants upon cutting with the widely used carbide tools.

1. The regression analysis concluded with a high degree of significance that the dependence of flank land wear upon temperature generated at the interface during cutting was valid for the speed range of 300 to 700 surface feet per minute. This correlation turned out to be approximately 90% significant for the finishing and roughing type cuts.

2. The high limit or end point was as hypothesized, the 600 to 700 surface feet per minute cutting. At this range there was a high rate of chip removal and also an increase in the amount of temperature evidenced. The results showed that the increase in flank land wear; however, the effect of the coolants, though significant in the analysis of variance test, showed through the application of the "t" test that the Dry condition was acturally

superior to both the Mist and Flow methods of cooling. This fact reinforces the discussion concerning the factors that too much heat is generated and that because of the high speed not enough time is available for the coolant to enter the interface and perform the function of heat removal. Both the flow and the mist cooling were ineffective by virtue of the rapid chip removal and instantaneous burning of the fluid or throwing off of the fluid as the cutting was performed. The cutting fluids, whether flow applied or mist applied did not have sufficient time to react and remove the heat generated during the high speeds.

3. The correlation for the dry cutting at the finishing speeds of 600 and 700 was very high, and therefore it is concluded that for the high speeds the wear on the cutting tool is directly related to the temperature generated at the high speeds with the dry condition.

4. At the speeds of 400 and 500 surface feet per minute, the correlation is very low with less than 90% confidence level that the variable of temperature is significant. Partial explanation of this conclusion is the peak points of the dry curve for temperature versus time. A more thorough analysis might be obtained if this cutting were allowed to be continued, and also if the sample taken were larger.

5. At speeds of 400 and 500 surface feet per minute

the correlation for the flow cutting was high, but the significance of the effect of the variable was less than 90% confidence level. This conclusion meant though there was good correlation between the wear and temperature variable, but because of the fit of the curve there was considerable doubt that at these particular speeds that the effect of the temperature variable was significant. The same type result was obtained for flow cutting at speeds of 600 and 700 surface feet per minute, i.e., a high degree of correlation with low significance of the effect of the variable.

6. The correlation for the mist cutting at 600 and 700 was highly significant, and similar to the dry cutting, the effect of the temperature variable was significant with a 95% to 99% confidence level. This meant that the linear type relationship for this cutting was both closely correlated and the temperature variable was highly significant.

7. At speeds of 400 and 500 surface feet per minute the correlation was good for wear versus temperature, but the significance of the effect of the variable was less than 90% as encountered with the Dry and Flow methods of cutting.

8. For the dependent variable of wear for the specific speeds of 400, 500, and the combined 600 and 700 surface feet per minute, it was established that both time and coolant were very significant at a 99% confidence level.

This meant that the analysis could be further extended to select the best or most superior type of coolant for the wear variable.

9. The "F" test for the temperature variable showed that the coolant effect was not significant for any 400, 500, or 600 and 700 combined surface feet per minute.

10. The results of the "t" test for the speed of 400 surface feet per minute showed that both the mist type and the flow type cooling are significantly different from the dry type cutting. The degree of significance is 99%, which means that we are accepting a 1% error im making this conclusion. The flow cutting is also significantly different from the mist cutting to a 99% level. This difference is based on the least amount of wear, and for the speed of 400 surface feet per minute we can conclude with 99% significance that the flow method of cooling is superior with respect to flank land wear.

11. For the speed of 500 surface feet per minute, results showed that the flow method differs significantly from the dry and mist mthods with a level of 99% confidence. The mist and dry conditions do not have significant difference. Therefore, we can conclude that the flow method is superior to both dry and mist for wear at 500 surface feet and that dry and mist cutting are not significantly different.

12. For the combined speeds of 600 and 700 surface feet per minute, we conclude that the dry condition is superior since it differs significantly from both flow and mist methods at a 99% confidence level. The flow method is next in superiority since it differs significantly from mist at a 99% confidence level. All of these are used for their effect on flank land wear.

13. For the speed of 300 surface feet per minute, it is concluded that both mist and flow differ significantly from dry cutting to a 99.9% confidence level, but do not differ significantly when compared to each other. Therefore, for a speed of 300 we can only state that mist and flow are better than dry, but neither superior to each other.

14. The correlation analysis showed that the coefficient of correlation for surface finish versus temperature was very low and not significant; neither was the effect of the temperature variable or speed significant in that the confidence level was less than 90%. The "F" test of the analysis of variance also showed that the coolants had low significance of 90% when compared with the variation within.

15. The correlation between the wear and the speed for the high speeds was inverse. This meant that as the speed was increased, the wear was decreased, which is not unreasonable, especially in this investigation in which

the high speeds were of a finishing type nature with one-half the feed rate of the lower or rough cuts and a depth of cut over 3 times less than the roughing type of cut.

16. In comparison of speed ranges of 400 and 500 surface feet per minute the speed-wear relationship was direct, i.e., as speed went up, wear went up, which is also valid since the same type of conditions were present for the lower speeds of 400 and 500 surface feet per minute. This effect was established previously, during dry cutting by Downing in his report on feeds and speeds for optimization.

DISCUSSION OF CONCLUSIONS

Although the correlation could have been higher, in conclusion I, the author, would like to mention that the sample in itself was limited, and that a larger population might have been more conclusive. The cutting situation was such that after each minute the tool was removed, and hence the three minute length was not a continuous cutting interval. This certainly accounted for the peak values of the curves plotted for temperature versus time at such speeds as 400 surface feet per minute for the Mist condition. Since the tool was removed after each minute, each setup had to be considered as separate, and therefore the time interval was subjected to a variance caused by the change in setups. Also, since the cutting was not continuous for the entire three minute span, a problem of time series analysis became ardent. Some of the curves such as the 400 surface feet per minute Dry analysis might have shown a general build up of temperature with inflection points as the cutting progressed instead of the peaking of the curve, at a certain interval, which was the two minute point in this case.

The effect of the chatter of the lathe used in the experiment must also be considered when analyzing the data. This effect was such that the response of the temperature recorder was subjected to fluctuations which might have been instrumental in precise recordings of the temperature generated during the cutting intervals.

The subject of human error was also an important consideration in the final analysis of the results. Since the thermocouple had to be manually placed next to the tool and insulated from the tool holder, setup changes at the one minute intervals certainly did not duplicate themselves and introduced variation within the experiment. This type of error is also present in recording of the data, both for the temperature and the wear readings as well as the surface finish. The variability was recognized by the author and considered to be low enough or of such a relatively constant nature that if a variation existed of around one to two per cent, that this effect could be accepted for the investigation.

In analyzing the results of the test, the factors that exerted an influence upon the results should be enumerated so a clear understanding exists for accurate review of this investigation. As mentioned previously, the author decided to establish end points or maximum or minimum points which were limits of the effect of conventional coolants. The low limit was that of the speed variable of 300 surface feet per minute. This speed, as has been pointed out by other authors such as Shaw, Sluhan, and others, is the end range of the influence of boundary lubrication. At speeds lower than 300 surface feet per minute, the problem in metal cutting does not seem to be that of heat removal as much as being able to form a low shear strength film which provides the necessary "boundary lubrication" and hence reduces friction, thereby greatly assisting in prolonging the tool life or generating better surface finish. As the speeds and feeds increase as illustrated by Downing, the temperature increases and since it has been stated that 99% of the work in metal cutting is transferred into heat, the problem of heat removal presents itself. It was therefore decided by the author that the range of speeds from 300 to 700 surface feet per minute would be the area for analysis of coolants or heat removers.

Another significant factor that must be mentioned in this investigation is that of direction of application of the cutting fluid. The author decided to use the method of application which is most commonly employed in industry today, that of directly on the top of the tool-chip area. There are other theories that consider other methods such as from the bottom of the tool through a capillary type action, and along the clearance face of the tool, which may be more effective. This is certainly a variable which has met with much discussion since the early work of Taylor in analyzing cutting fluid effectiveness. Since the method of application was the same throughout the investigation, this variable was then considered as a constant for the results, and not influential in the final analysis. By looking at the results of the "F" test for temperature, we can clearly see that the temperature variable is definitely one of an independent nature in this analysis, and it is a part of the factors that exert significance upon the dependent variable of wear. The variables of coolant and speed must be investigated on a more quantitive basis to fully see the effect on the temperature. In these results, then, we can say that the coolants did lower the temperature and that the speed increase did in some cases increase the temperature, but not how much the temperature was reduced by the coolant or how much the temperature was increased by the speed.

It was the purpose of this investigation to establish the temperature-wear relationship by analysis of coolants. The conclusions showed that the coolants did reduce the wear with a reduction in temperature despite the other factors that were involved in the analysis, such as speed, time, and the interactions thereof.

The use of the "t" test enabled the author to compare the three types of coolants for their effect upon the dependent variable of wear at the various speeds. This test was an analysis of the means of the three types of coolants for the entire three minutes of cutting. This meant that an average value was obtained for the cutting, even though the cutting was not continuous. By using the "t" test the coolants could then be compared to indicate superiority over the three minute interval.

The "F" test was used to establish the significant difference, if any, between the variables on the two factors, wear and temperature, and temperature and surface finish.

An overall analysis of variance was performed and the conclusions showed that all the variables, speed, time, coolant, and the speed-coolant interaction were very significant. The variable of speed had the highest "F" value with the coolant being the next. This meant that these variables, when compared with their variation within, did have an effect of high significance upon wear.

The same "F" test was run for the dependent variable of temperature and the conclusions showed high significance for speed and coolant but no significance for time or the speed-coolant interaction.

By using this type of test we could therefore conclude that for both temperature and wear, that coolant and speed had significant effect, which was originally hypothesized by the establishment of the degree of correlation for the entire speed range.

Because of the conclusions of the surface finish variable for the finishing cuts at the speeds of 600 and 700 surface feet per minute, it was hypothesized that the size of the sample was small and hence the results could not be taken as conclusive evidence. Another factor was the difference of the bars of the 4145 steel which were used, which although from the same heat, could have varied enough to cause variation in surface finish.

The factor of hardness was taken into consideration in the scope of the investigation, and similar to the direction of application of the cutting fluid was considered as a constant in this investigation.

Another area which could have exerted an influence was the rate of flow of coolant, which was kept at a constant for the flow cooling and the mist cooling. The type of coolant was also kept constant in order to keep this variation out of the actual experimental results. Finally, when making the regression analysis and the subsequent correlation, it was assumed that the wear variable was of a linear type relationship. The regression expression was X_1 (wear) = a (constant) plus b (regression coefficient) X_2 (temperature) plus c (regression coefficient) X_3 (speed).

It is entirely possible that the wear variable which has been established to be significantly correlated to the temperature variable might be of the expoential type relationship where the temperature variable might be raised to some power, negative or positive. This can be further realized if one pictures the shape of the typical wear curve for flank land wear. This area is one of possible further study, especially with relationship to a time series analysis.

The conclusions of this experiment did signify the correlation of the wear-temperature variables, which is very significant in that it is the initial type conclusion for cutting with carbide tools and using the three conventional methods of cooling.

RECOMMENDATIONS FOR FURTHER STUDY

As a result of this investigation the author would like to point out some areas that are connected with investigation which should be further considered:

1) Effect of rate of flow on the temperature-wear relationship of metal cutting.

2) The study of the direction of application of cutting fluid during metal cutting.

3) Analysis of different types of coolants with respect to their effect on temperature in metal cutting.

4) Analysis of the different grades of carbides and/or high speed steels and the temperature-wear relationship during metal cutting.

5) The effect on surface finish of the three types of methods of cooling - spray mist, flood, and air.

6) Mathematical analysis of the conventional wear curve for metal cutting-set-up of a possible equation.

7) Effect of the distance of mist applicator on temperature and wear of carbide tools.

8) Time-series analysis for continuous cutting with coolants for a carbide tool.

These areas are the major problem sectors that affected the investigation and which have little or no information available to the tool engineer. Much more valid statistical analysis could be applied to these areas in order to substantiate any findings or conclusions brought forth.

APPENDIX A

DATA

FEED	DEPTH	SPEED	TEMP.	COOL.	WEAR	SURF. FIN.	TIME
.010	.030	600	14.2	Dry	3.4	42	1 Min.
.010	.030	600	15.5	Dry	5.5	40	2 Min.
.010	.030	600	18.1	Dry	6.7	90	3 Min.
.010	.030	600	15.5	Flood	3.3	70	1 Min.
.010	.030	600	12.8	Flood	4.4	35	2 Min.
.010	.030	600	12.4	Flood	5.0	58	3 Min.
.010	.030	600	10.8	Flood	3.0	65	1 Min.
.010	.030	600	13.0	Flood	4.4	48	2 Min.
.010	.030	600	13.0	Dry	6.0	60	3 Min.
.010	.030	600	11.8	Mist	5.8	110	1 Min.
.010	.030	600	13.0	Mist	6.1	65	2 Min.
.010	.030	600	14.8	Mist	7.0	64	3 Min.
.010	.030	600	12.8	Mist	4.5	70	1 Min.
.010	.030	600	13.2	Mist	5.7	80	2 Min.
.010	.030	600	13.8	Mist	8.5	55	3 Min.
.010	.030	700	12.36	Dry	4.1	40	1 Min.
.010	.030	700	12.80	Dry	5.1	55	2 Min.
.010	.030	700	12.9	Dry	6.6	68	3 Min.
.010	.030	700	14.7	Dry	4.8	45	1 Min.
.010	.030	700	15.7	Dry	6.0	58	2 Min.
.010	.030	700	15.7	Dry	7.5	84	3 Min.
.010	.030	700	14.5	Flood	4.5	50	1 Min.

FEED	DEPTH	SPEED	TEMP.	COOL.	WEAR	SURF. FIN.	TIME
.010	.030	700	14.4	Flood	6.1	60	2 Min.
.010	.030	700	14.4	Flood	7.8	90	3 Min.
.020	.100	300	11.6	Dry	10.3	210	1 Min.
.020	.100	300	11.44	Dry	10.4	230	2 Min.
.020	.100	300	11.36	Dry	20.9	240	3 Min.
.020	.100	300	11.6	Dry	10.0	210	1 Min.
.020	.100	300	12.0	Dry	13.0	220	2 Min.
.020	.100	300	12.5	Dry	21.8	240	3 Min.
.020	.100	300	12.4	Flood	4.0	210	1 Min.
.020	.100	300	12.6	Flood	4.1	220	2 Min.
.020	.100	300	12.6	Flood	8.3	230	3 Min.
.020	.100	300	12.2	Flood	6.8	210	1 Min.
.020	.100	300	12.4	Flood	8.1	240	2 Min.
.020	.100	300	12.4	Flood	8.3	240	3 Min.
.020	.100	300	12.0	Mist	4.4	200	1 Min.
.020	.100	300	14.4	Mist	6.4	220	2 Min.
.020	.100	300	13.6	Mist	7.7	170	3 Min.
.020	.100	300	14.0	Mist	3.8	220	1 Min.
.020	.100	300	11.8	Mist	5.4	185	2 Min.
.020	.100	300	12.4	Mist	7.6	190	3 Min.
.020	.100	300	12.0	Mist	3.0	210	1 Min.
.020	.100	300	16.0	Mist	6.7	220	2 Min.
.020	.100	300	12.0	Mist	7.0	200	3 Min.
.020	.100	400	13.0	Dry	17.7	210	1 Min.

FEED	DEPTH	SPEED	TEMP.	COOL.	WEAR	SURF. FIN.	TIME
.020	.100	400	14.0	Dry	25.2	230	2 Min.
.020	.100	400	13.7	Dry	29.7	250	3 Min.
.020	.100	400	13.2	Dry	16.0	280	1 Min.
.020	.100	400	18.4	Dry	20.8	290	2 Min.
.020	.100	400	15.2	Dry	25.1	280	3 Min.
.020	.100	400	14.5	Dry	15.5	220	1 Min.
.020	.100	400	20.9	Dry	18.8	280	2 Min.
.020	.100	400	16.8	Dry	23.5	280	3 Min.
.020	.100	400	12.96	Flood	2.0	300	1 Min.
.020	.100	400	15.0	Flood	7.2	200	2 Min.
.020	.100	400	13.0	Flood	10.1	220	3 Min.
.020	.100	400	16.8	Flood	2.5	370	1 Min.
.020	.100	400	15.2	Flood	5.0	250	2 Min.
.020	.100	400	16.0	Flood	5.3	160	3 Min.
.020	.100	400	14.5	Flood	6.5	280	1 Min.
.020	.100	400	14.0	Flood	7.5	280	2 Min.
.020	.100	400	15.0	Flood	13.2	300	3 Min.
.020	.100	400	14.0	Mist	8.2	190	1 Min.
.020	.100	400	12.5	Mist	9.5	170	2 Min.
.020	.100	400	12.8	Mist	14.5	215	3 Min.
.020	.100	400	12.6	Mist	9.1	170	1 Min.
.020	.100	400	12.6	Mist	12.3	170	2 Min.
.020	.100	400	12.9	Mist	15.6	260	3 Min.
.020	.100	400	12.4	Mist	12.9	215	1 Min.

FEED	DEPTH	SPEED	TEMP.	COOL.	WEAR	SURF. FIN.	TIME
.020	.100	400	13.4	Mist	15.6	210	2 Min.
.020	.100	400	13.8	Mist	16.0	235	3 Min.
.020	.100	500	12.1	Dry	19.1	220	1 Min.
.020	.100	500	13.4	Dry	22.7	360	2 Min.
.020	.100	500	14.8	Dry	33.4	440	3 Min.
.020	.100	500	12.2	Dry	28.4	230	1 Min.
.020	.100	500	13.7	Dry	31.6	340	2 Min.
.020	.100	500	14.9	Dry	36.1	400	3 Min.
.020	.100	500	13.8	Flow	15.2	200	1 Min.
.020	.100	500	14.4	Flow	17.1	220	2 Min.
.020	.100	500	13.8	Flow	28.4	240	3 Min.
.020	.100	500	14.2	Flow	21.6	100	1 Min.
.020	.100	500	14.0	Flow	23.7	115	2 Min.
.020	.100	500	14.0	Flow	25.4	150	3 Min.
.020	.100	500	13.3	Mist	18.7	240	1 Min.
.020	.100	500	13.61	Mist	29.2	280	2 Min.
.020	.100	500	13.41	Mist	31.2	340	3 Min.
.020	.100	500	13.8	Mist	23.1	240	1 Min.
.020	.100	500	14.0	Mist	29.3	350	2 Min.
.020	.100	500	13.8	Mist	34.3	340	3 Min.
.010	.030	600	11.4	Dry	2.5	20	1 Min.
.010	.030	600	12.8	Dry	4.8	43	2 Min.
.010	.030	600	13.24	Dry	6.5	120	3 Min.
.010	.030	600	13.24	Dry	3.1	60	1 Min.

FEED	DEPTH	SPEED	TEMP.	COOL.	WEAR	SURF. FIN.	TIME
.010	.030	600	16.2	Dry	4.5	46	1 Min.
.010	.030	600	17.0	Dry	5.8	52	3 Min.
.010	.030	700	11.6	Flood	6.7	50	1 Min.
.010	.030	700	12.6	Flood	7.8	55	2 Min.
.010	.030	700	12.6	Flood	14.2	70	3 Min.
.010	.030	700	12.0	Mist	5.0	52	1 Min.
.010	.030	700	14.0	Mist	6.9	65	2 Min.
.010	.030	700	15.6	Mist	11.2	75	3 Min.
.010	.030	700	11.2	Mist	4.5	55	1 Min.
.010	.030	700	12.0	Mist	10.1	60	2 Min.
.010	.030	700	12.5	Mist	11.3	80	3 Min.

AVERAGE VALUES

FEED	DEPTH	SPEED	TEMP.	COOL.	WEAR	SURF. FIN.	TIME
.020	.100	300	1485	Dry	10.1	210	1 Min.
.020	.100	300	1500	Dry	11.7	225	2 Min.
.020	.100	300	1530	Dry	21.3	235	3 Min.
.020	.100	300	1580	Flood	5.4	210	1 Min.
.020	.100	300	1608	Flood	6.2	234	2 Min.
.020	.100	300	1608	Flood	8.3	235	3 Min.
.020	.100	300	1675	Mist	3.7	210	1 Min.
.020	.100	300	1820	Mist	6.4	208	2 Min.
.020	.100	300	1635	Mist	7.7	186	3 Min.
.020	.100	400	1750	Dry	16.4	236	1 Min.
.020	.100	400	2310	Dry	21.3	217	2 Min.
.020	.100	400	1970	Dry	25.9	270	3 Min.
.020	.100	400	1910	Flood	3.6	303	1 Min.
.020	.100	400	1900	Flood	6.5	243	2 Min.
.020	.100	400	1930	Flood	9.5	227	3 Min.
.020	.100	400	1675	Mist	10.0	192	1 Min.
.020	.100	400	1650	Mist	12.4	183	2 Min.
.020	.100	400	1662	Mist	15.4	23	3 Min.
.020	.100	500	1550	Dry	23.7	250	1 Min.
.020	.100	500	1740	Dry	27.1	350	2 Min.
.020	.100	500	1920	Dry	34.7	420	3 Min.
.020	.100	500	1810	Flood	18.4	150	1 Min.

FEED	DEPTH	SPEED	TEMP.	COOL.	WEAR	SURF. FIN.	TIME
.020	.100	500	1840	Flood	20.4	167	2 Min.
.020	.100	500	1795	Flood	26.9	195	3 Min.
.020	.100	500	1740	Mist	20.9	240	1 Min.
.020	.100	500	1785	Mist	29.2	315	2 Min.
.020	.100	500	1770	Mist	32.7	340	3 Min.
.010	.030	600	1668	Dry	3.0	41	1 Min.
.010	.030	600	1910	Dry	4.93	43	2 Min.
.010	.030	600	2050	Dry	6.33	67	3 Min.
.010	.030	600	1538	Flood	3.1	37	1 Min.
.010	.030	600	1663	Flood	4.4	46	2 Min.
.010	.030	600	1635	Flood	5.5	59	3 Min.
.010	.030	600	1580	Mist	5.1	90	1 Min.
.010	.030	600	1690	Mist	5.9	73	2 Min.
.010	.030	600	1850	Mist	7.8	59	3 Min.
.010	.030	700	1740	Dry	4.2	42	1 Min.
.010	.030	700	1840	Dry	5.6	54	2 Min.
.010	.030	700	1850	Dry	7.1	84	3 Min.
.010	.030	700	1675	Flood	5.6	50	1 Min.
.010	.030	700	1740	Flood	6.9	58	2 Min.
.010	.030	700	1740	Flood	11.0	80	3 Min.
.010	.030	700	1485	Mist	4.7	53	1 Min.
.010	.030	700	1675	Mist	8.5	62	2 Min.
.010	.030	700	1810	Mist	11.3	78	3 Min.

APPENDIX B

TOOL GEOMETRY

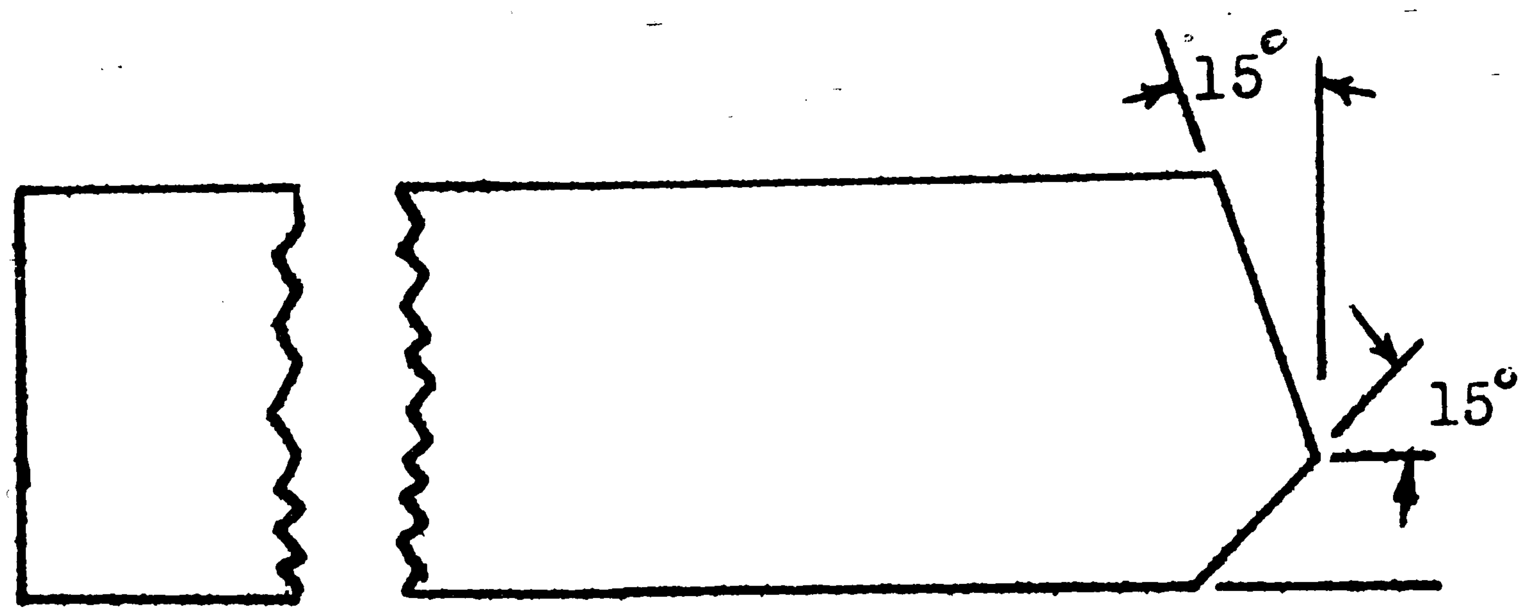
A. Top View - Tool Holder

B. Side View - Tool Holder

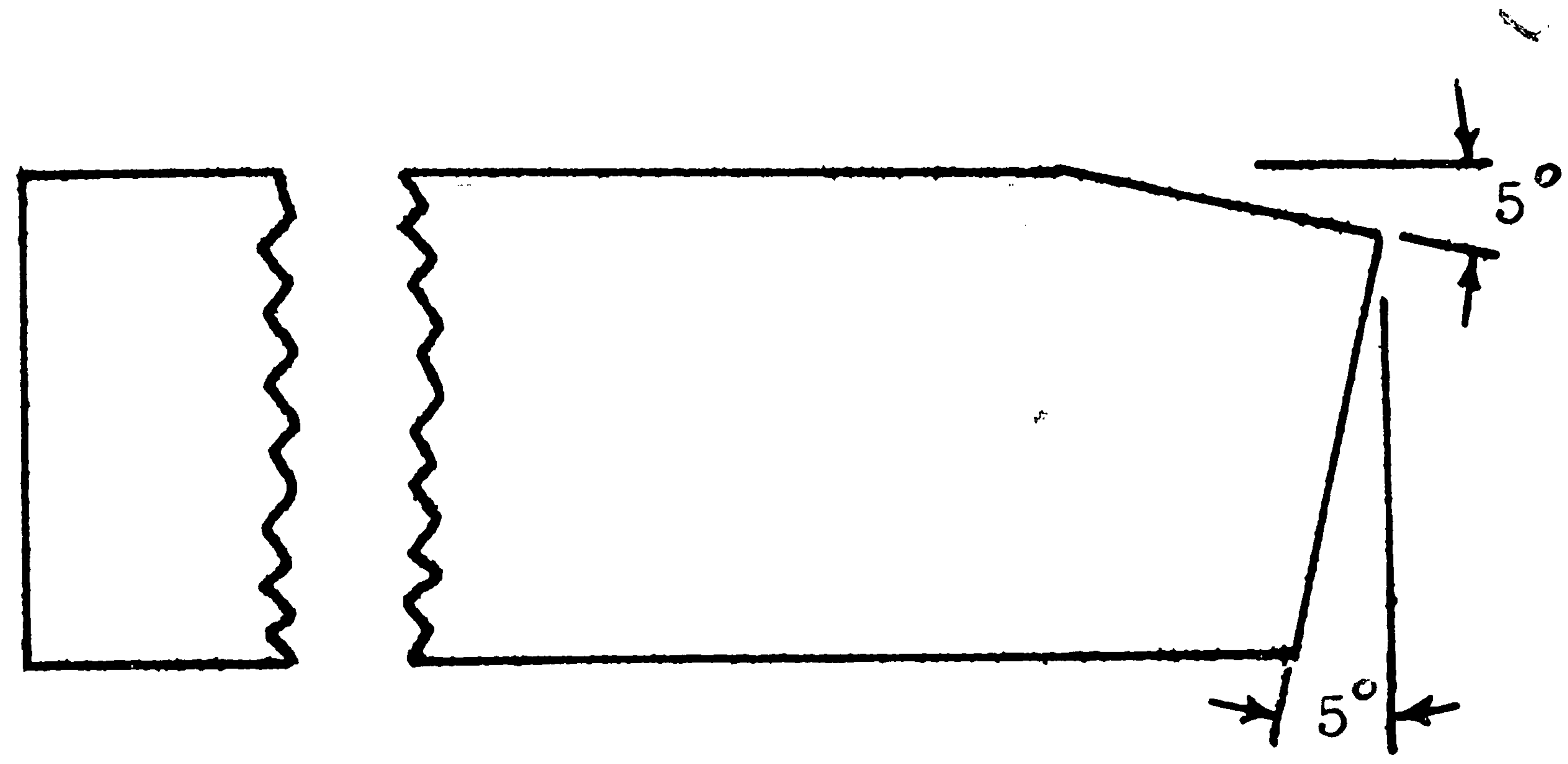
C. Top View - Tool

D. Side View - Tool

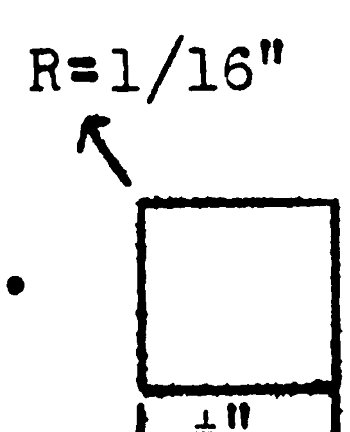
A.



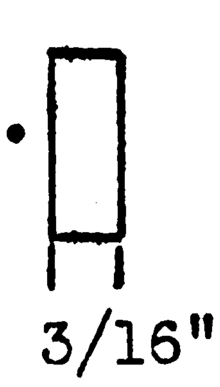
B.



C.



D.



MACHINE COMPUTER READINGS

DRY	300	SFPM	Rough	Life = 6 min. for .030 wear 3 min. for .015 wear
	400	SFPM	Rough	Life = 1.8 min. for .030 wear .9 min. for .015 wear
WET	300	SFPM	Rough	Life = 40 min. for .030 wear 3 min. for .005 wear
	400	SFPM	Rough	Life = 9 mim. for .030 wear
DRY	500	SFPM	Fine	Life = 12 min. for .030 wear 1 min. for .005 wear
	600	SFPM	Fine	Life = 5.5 min. for .030 wear 2.1 min. for .015 wear
	700	SFPM	Fine	Life = 2.2 min. for .030 wear 1.1 min. for .015 wear
WET	500	SFPM	Fine	Life = 1.25 hrs. for .030 wear 5.5 min. for .005 wear
	600	SFPM	Fine	Life = 30 min. for .030 wear 2.3 min. for .005 wear
	700	SFPM	Fine	Life = 13 min. for .030 wear 1.0 min. for .005 wear

APPENDIX C

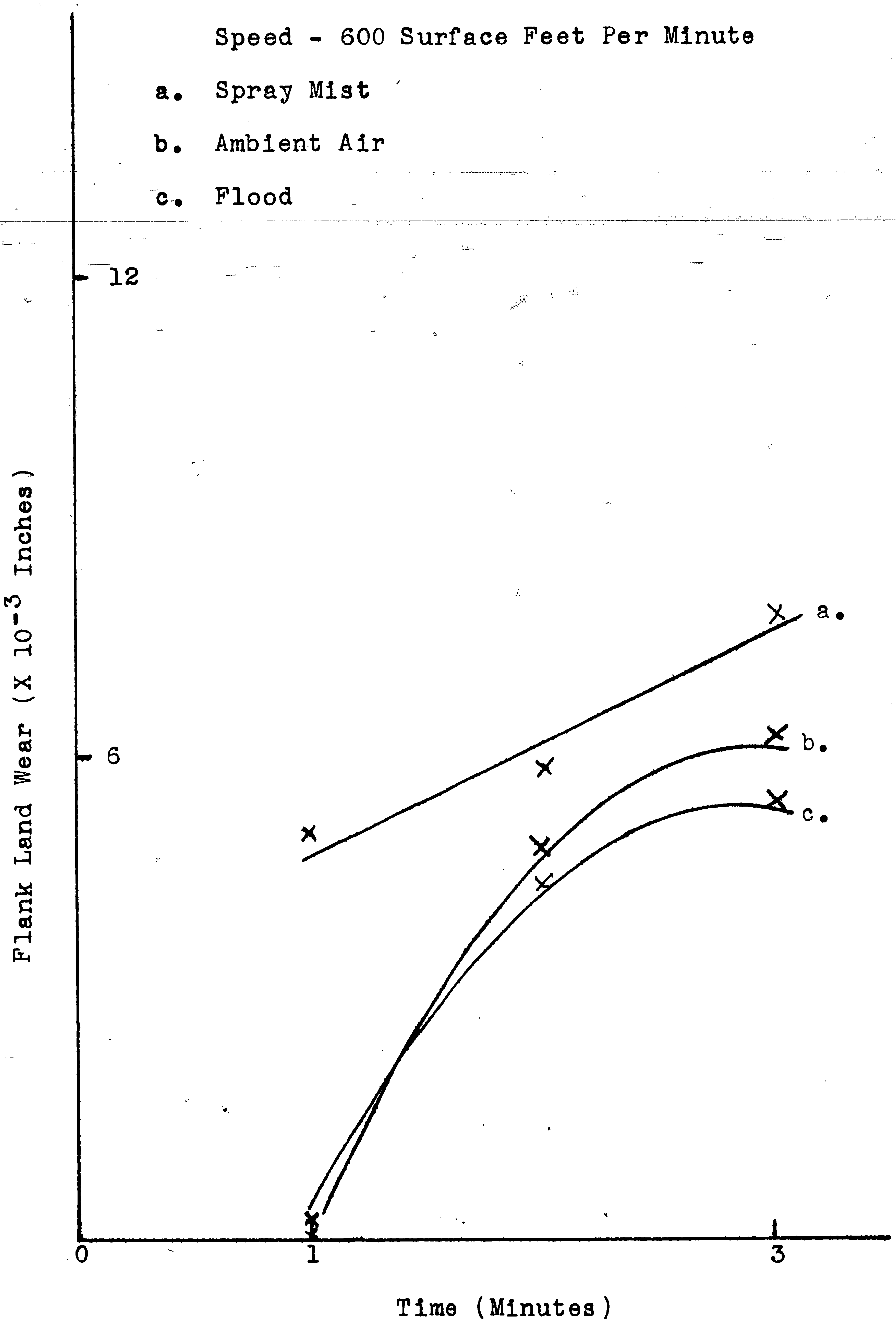
Graph I. Flank Land Wear vs. Time

Speed - 600 Surface Feet Per Minute

a. Spray Mist

b. Ambient Air

c. Flood



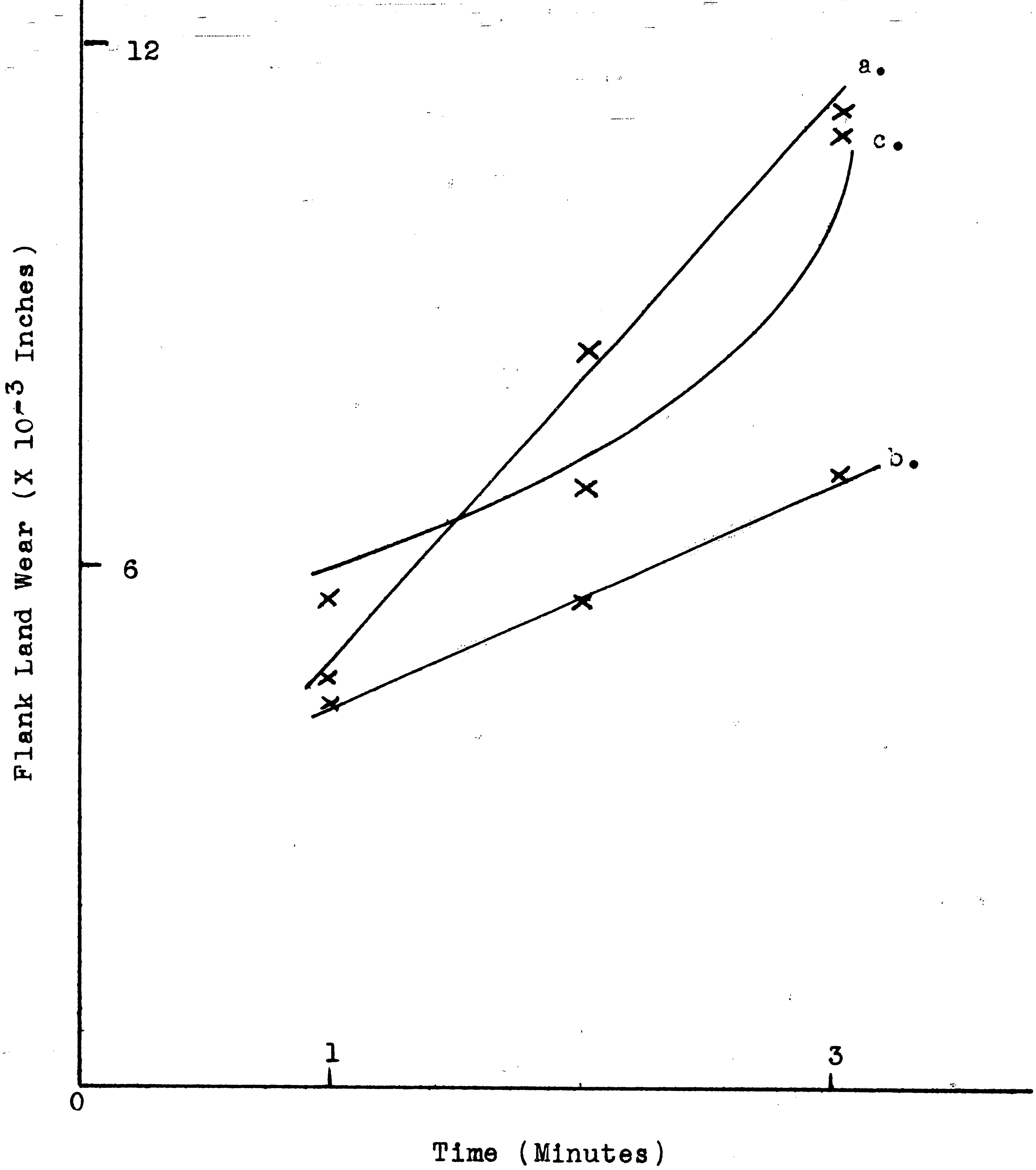
Graph II. Fland Land Wear vs. Time

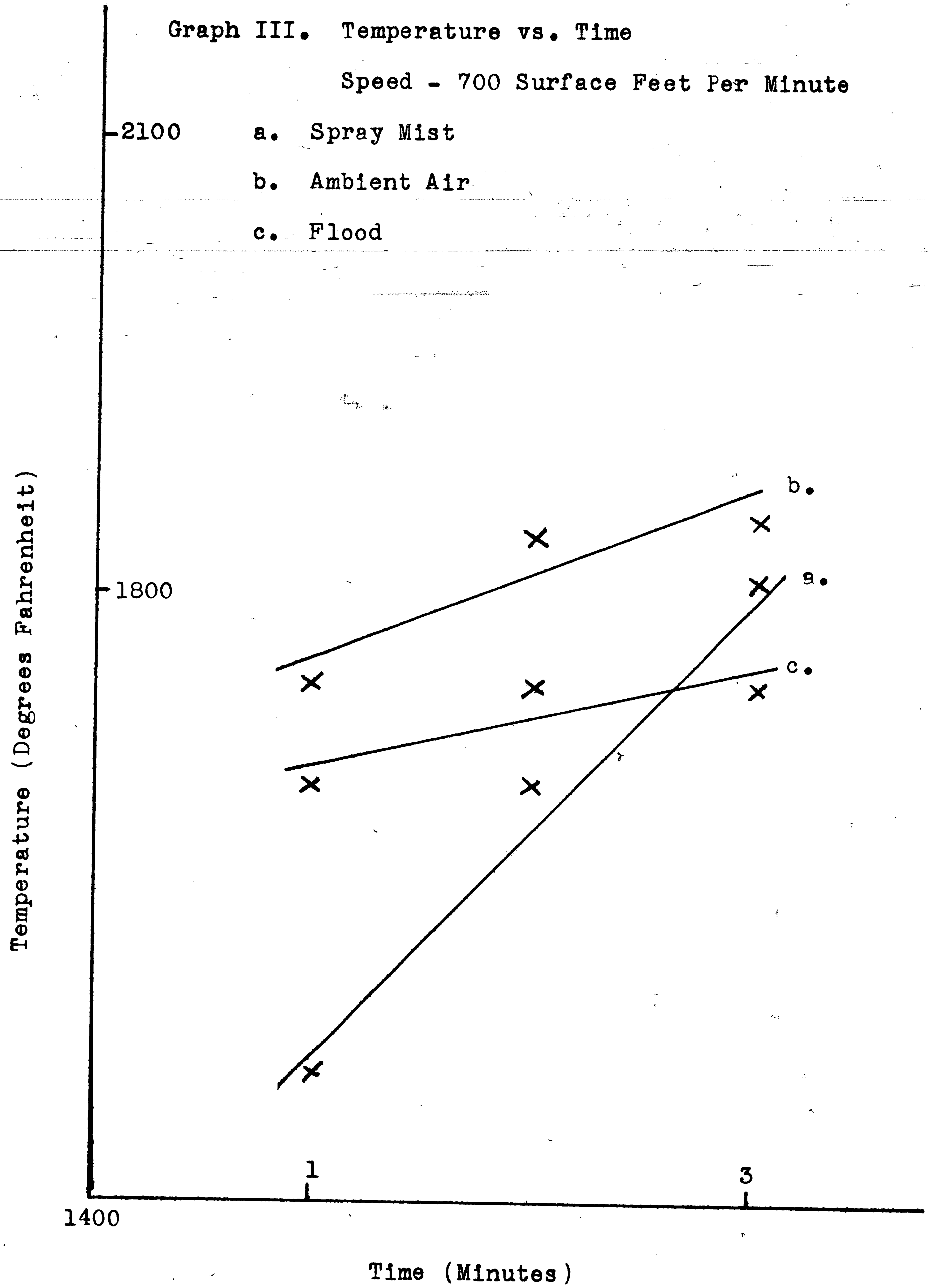
Speed - 700 Surface Feet Per Minute

a. Spray Mist

b. Ambient Aip

c. Flood




Graph III. Temperature vs. Time
Speed - 700 Surface Feet Per Minute
2100
a. Spray Mist
b. Ambient Air
c. Flood
1800
1400
b.
a.
c.
1
3
Temperature (Degrees Fahrenheit)
Time (Minutes)

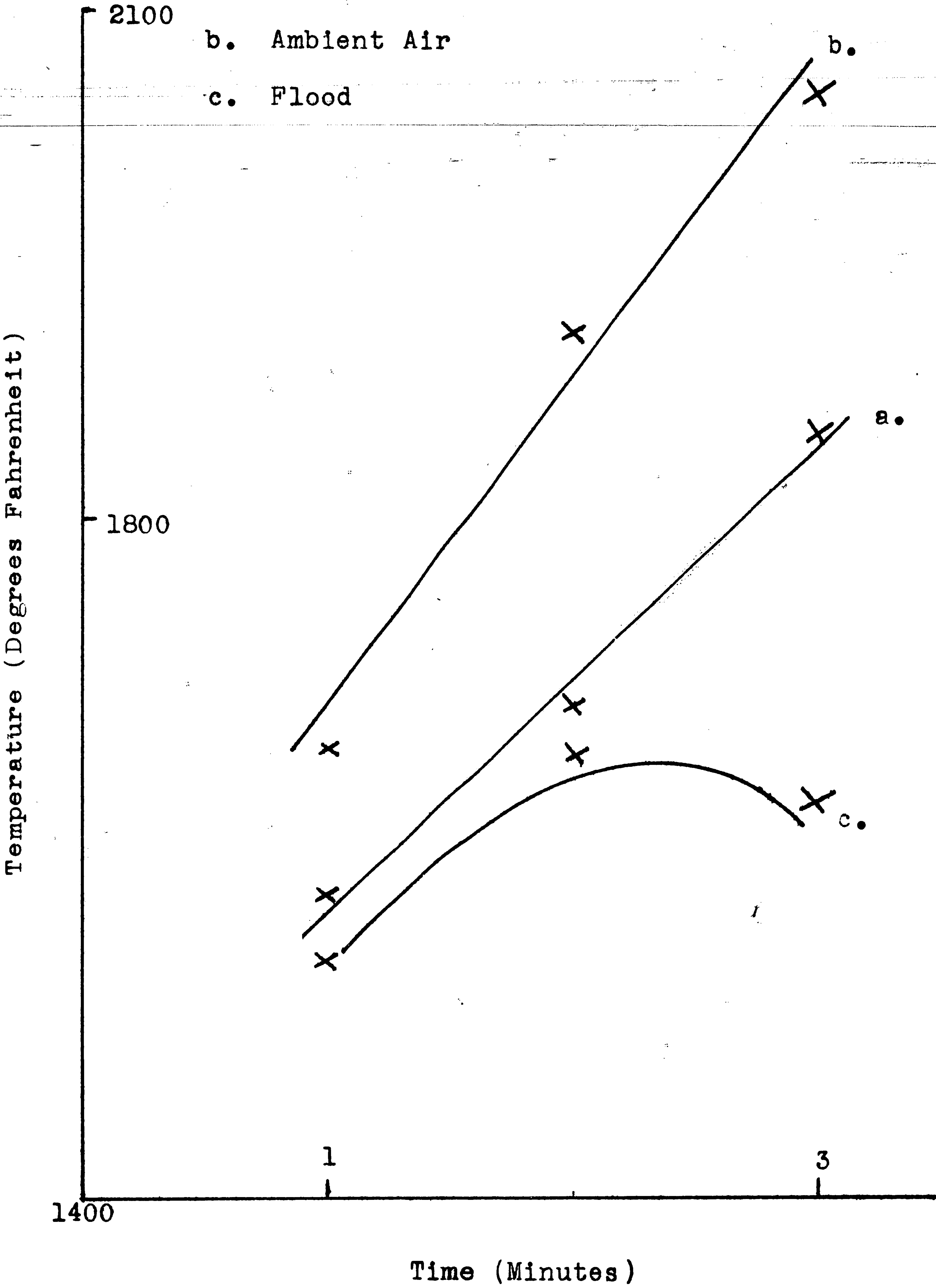
Graph IV. Temperature vs. Time

Speed - 600 Surface Feet Per Minute

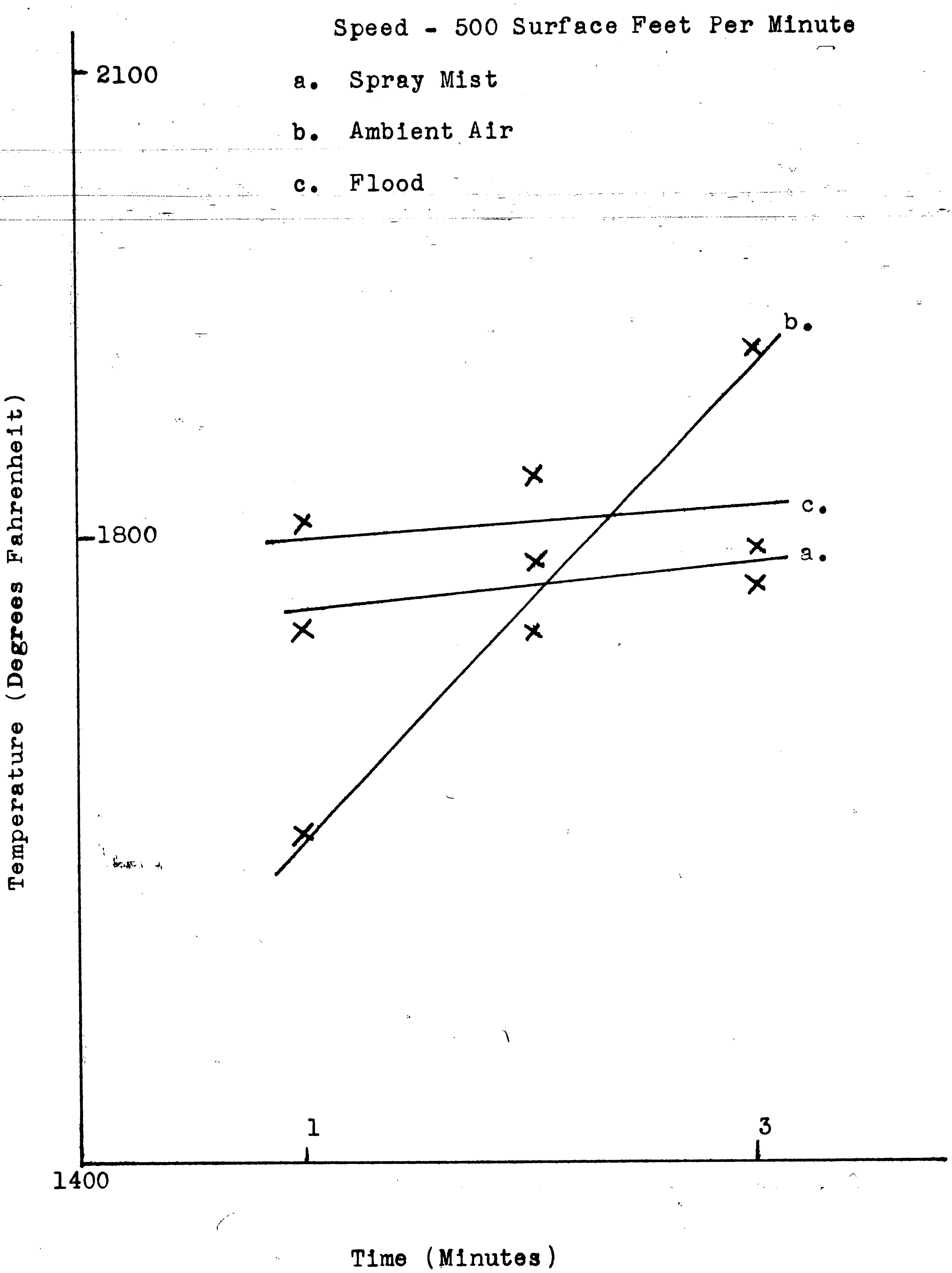
a. Spray Mist

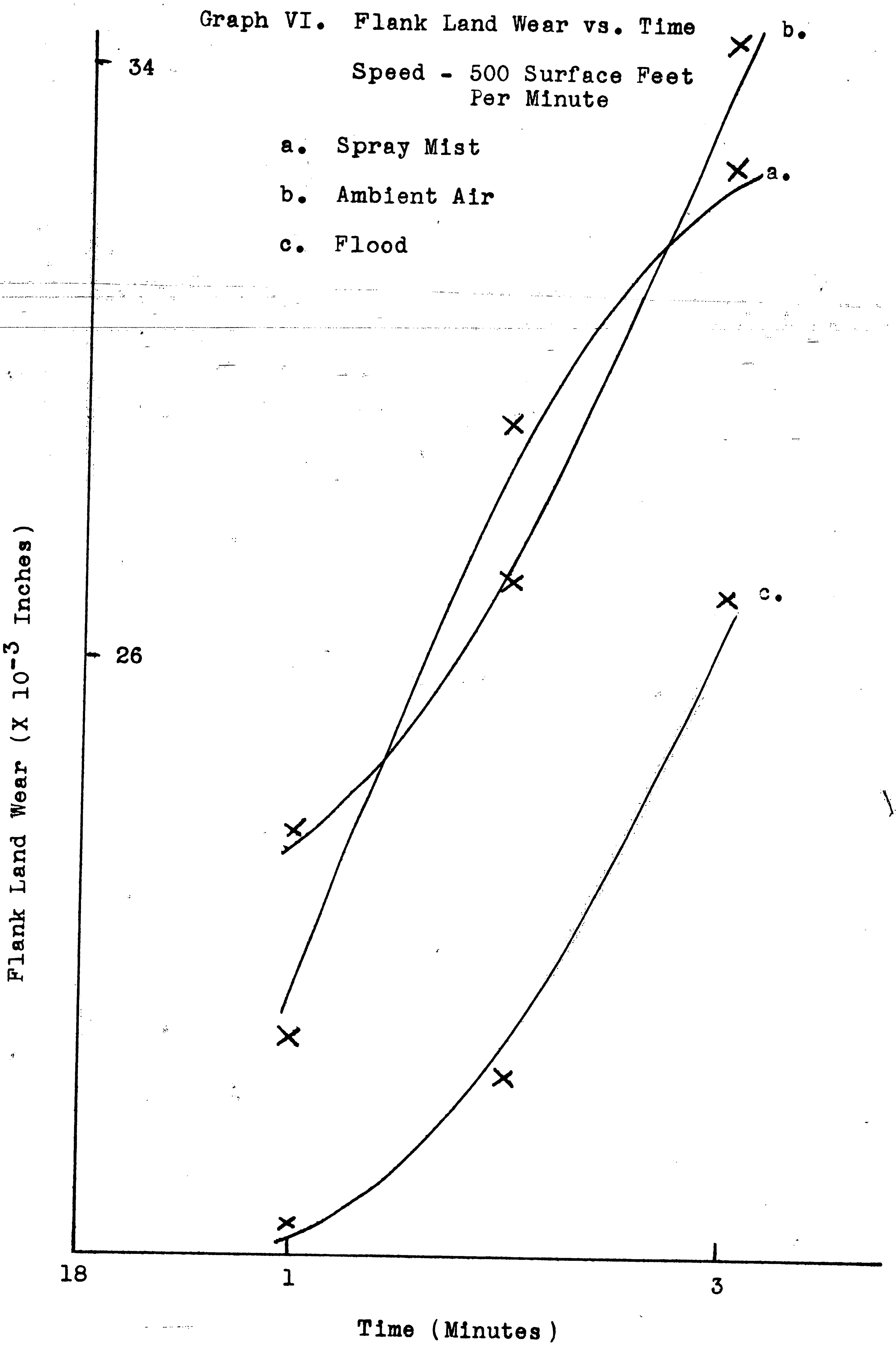
b. Ambient Air

c. Flood



Graph V. Temperature vs. Time





Graph VI. Flank Land Wear vs. Time
Speed - 500 Surface Feet Per Minute
a. Spray Mist
b. Ambient Air
c. Flood
34
26
18
Flank Land Wear (X 10^{-3} Inches)
1
3
Time (Minutes)
a.
b.
c.

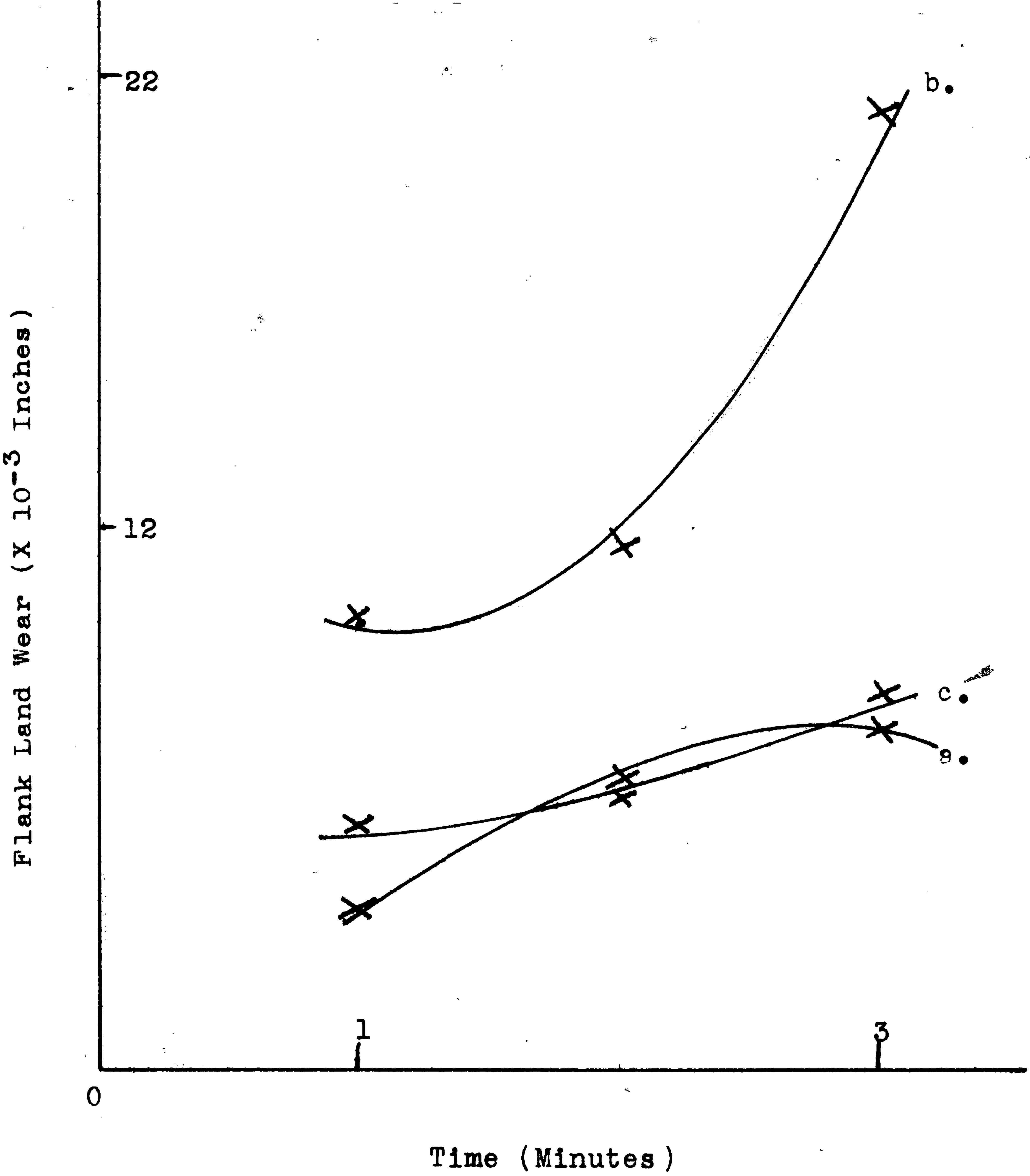
Graph VII. Flank Land Wear vs. Time

Speed - 300 Surface Feet Per Minute

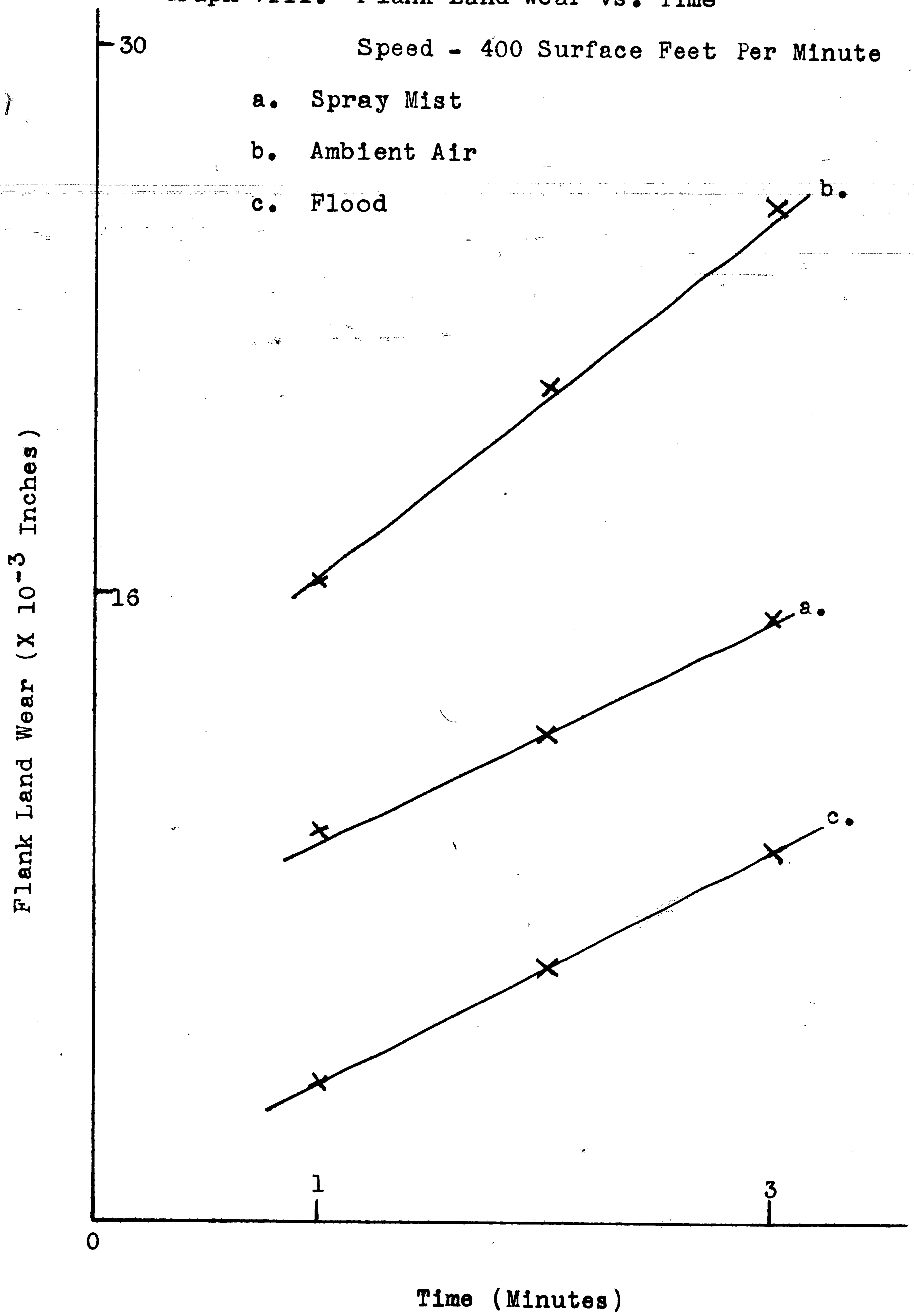
a. Spray Mist

b. Ambient Air

c. Flood



Graph VIII. Flank Land Wear vs. Time



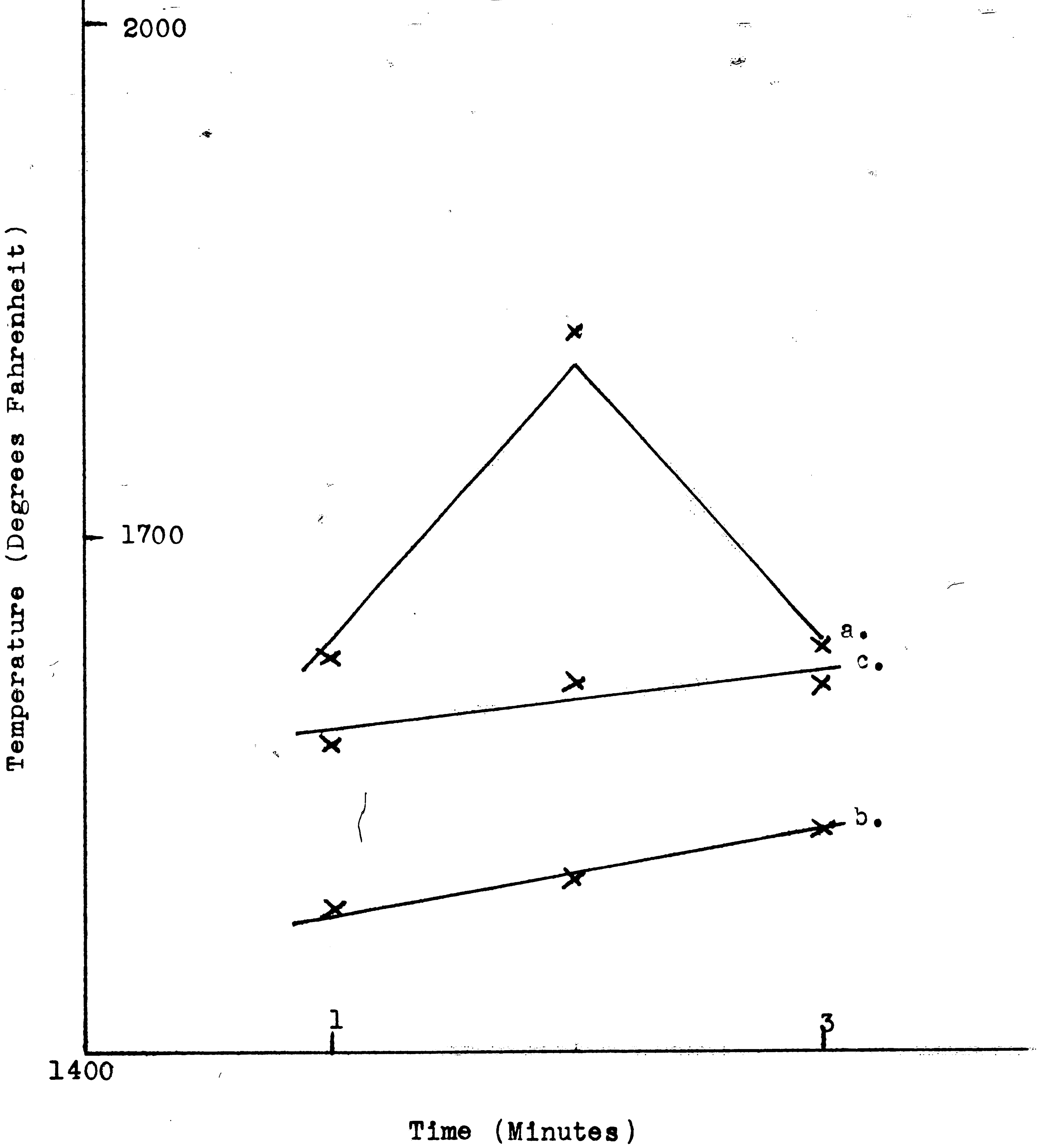
Graph IX. Temperature vs. Time

Speed - 300 Surface Feet Per Minute

a. Spray Mist

b. Ambient Air

c. Flood



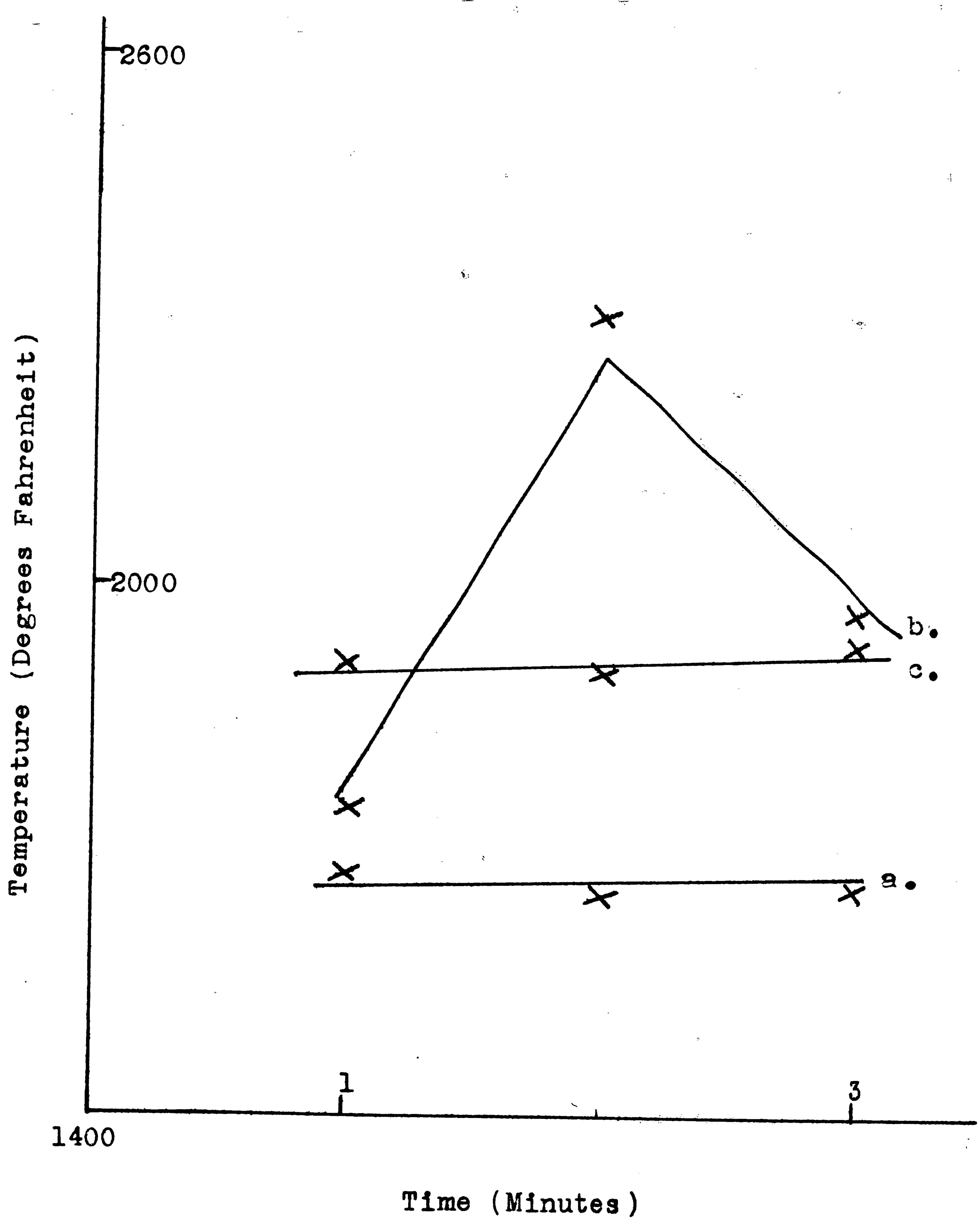
Graph X. Temperature vs. Time

Speed - 400 Surface Feet Per Minute

a. Spray Mist

b. Ambient Air

c. Flood



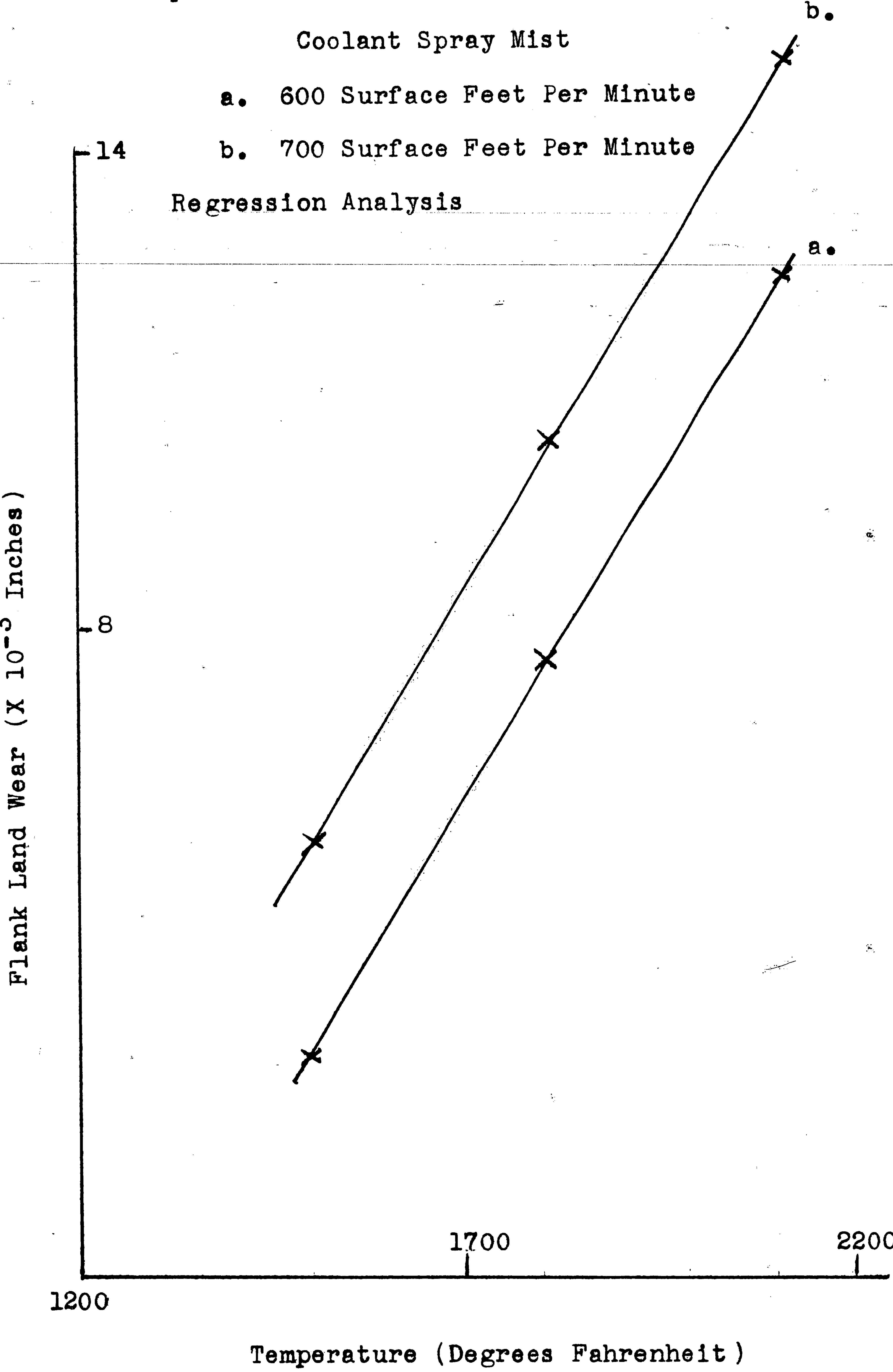
Graph XI. Flank Land Wear vs. Temperature

Coolant Spray Mist

a. 600 Surface Feet Per Minute

b. 700 Surface Feet Per Minute

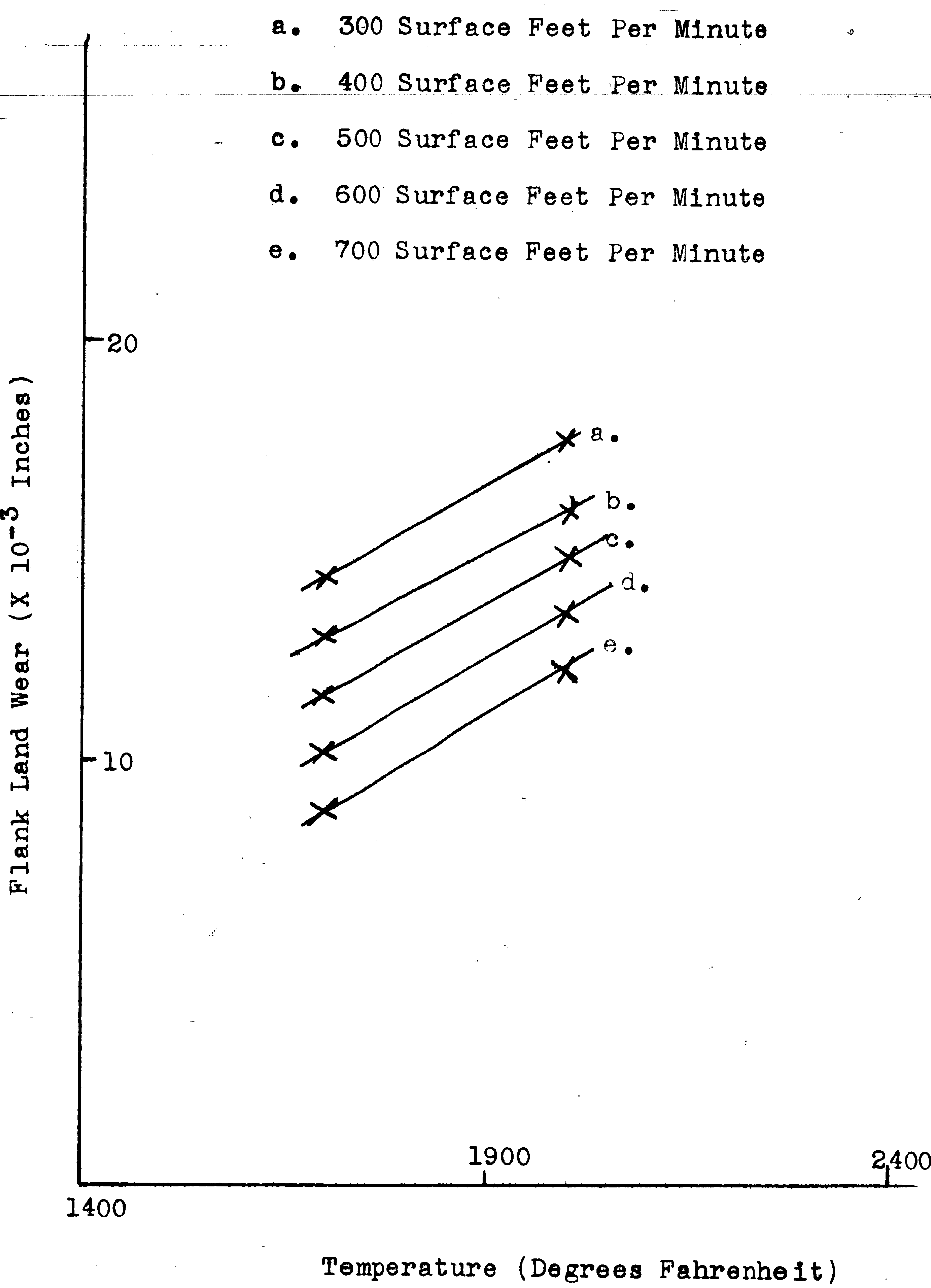
Regression Analysis



Graph XII. Flank Land Wear vs. Temperature

(All Coolants)

Regression Analysis



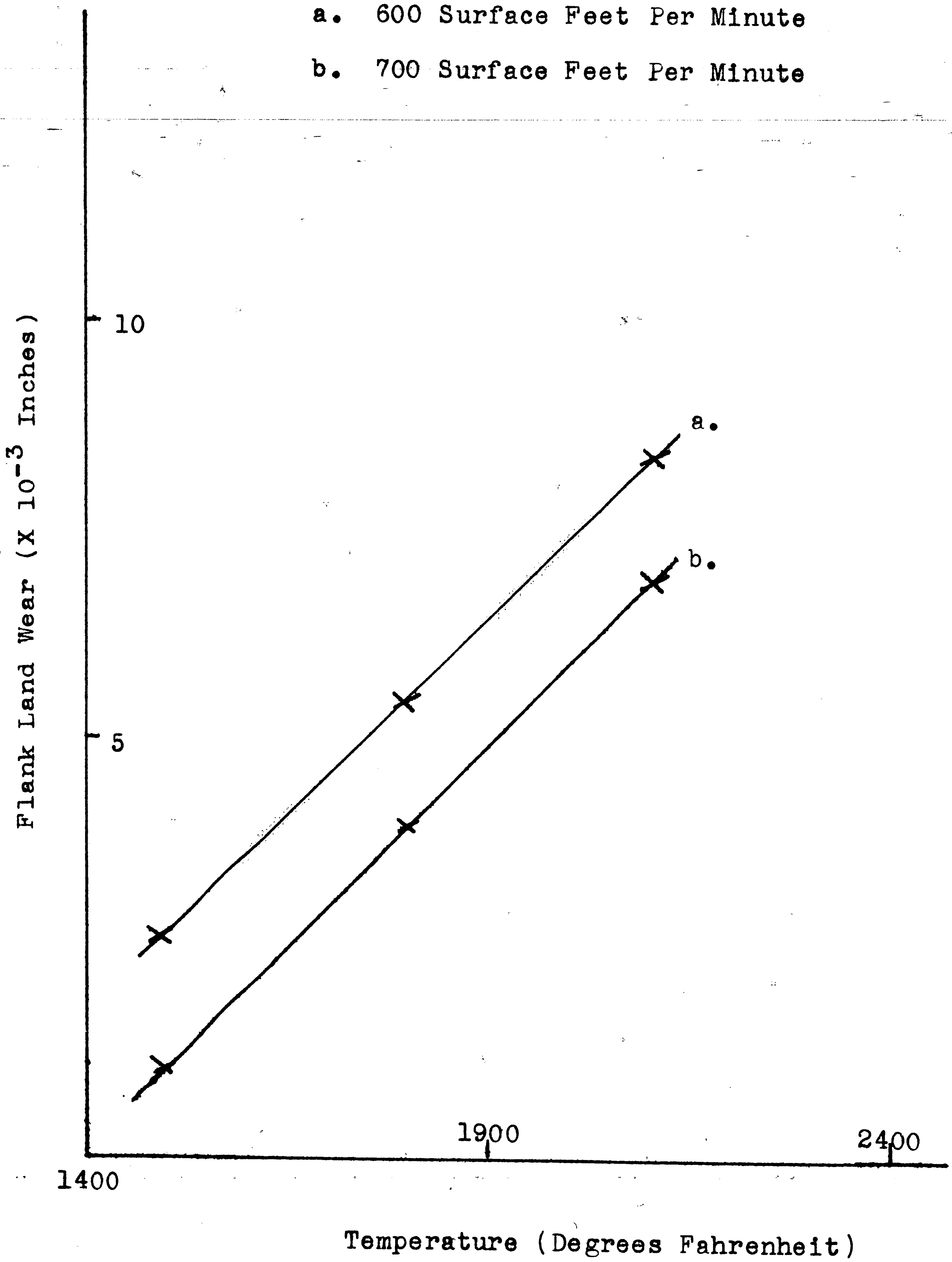
Graph XIII. Flank Land Wear vs. Temperature

Coolant - Ambient Air

Regression Analysis

a. 600 Surface Feet Per Minute

b. 700 Surface Feet Per Minute



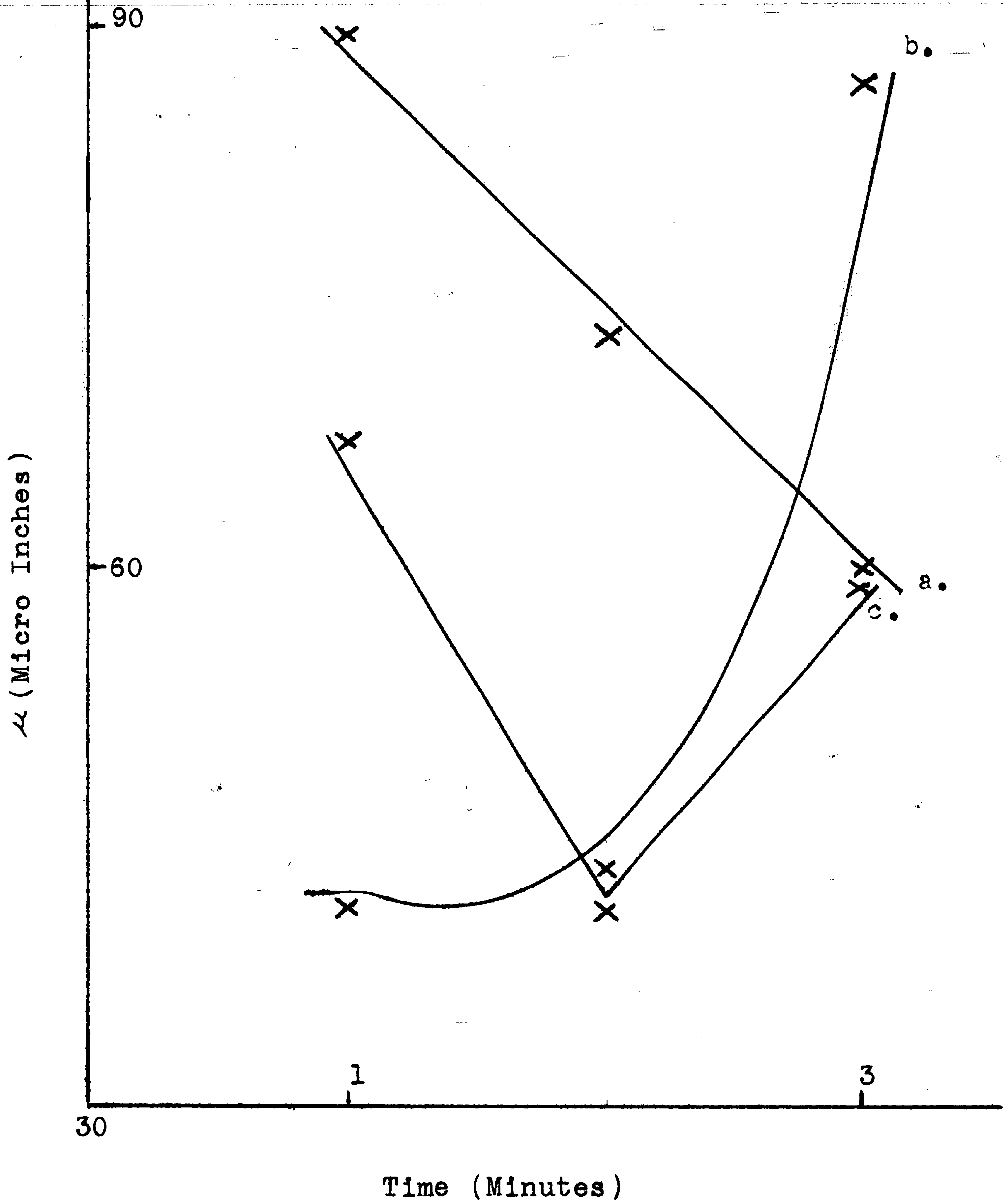
Graph XIV. Surface Finish vs. Time

Speed - 600 Surface Feet Per Minute

a. Spray Mist

b. Ambient Air

c. Flood



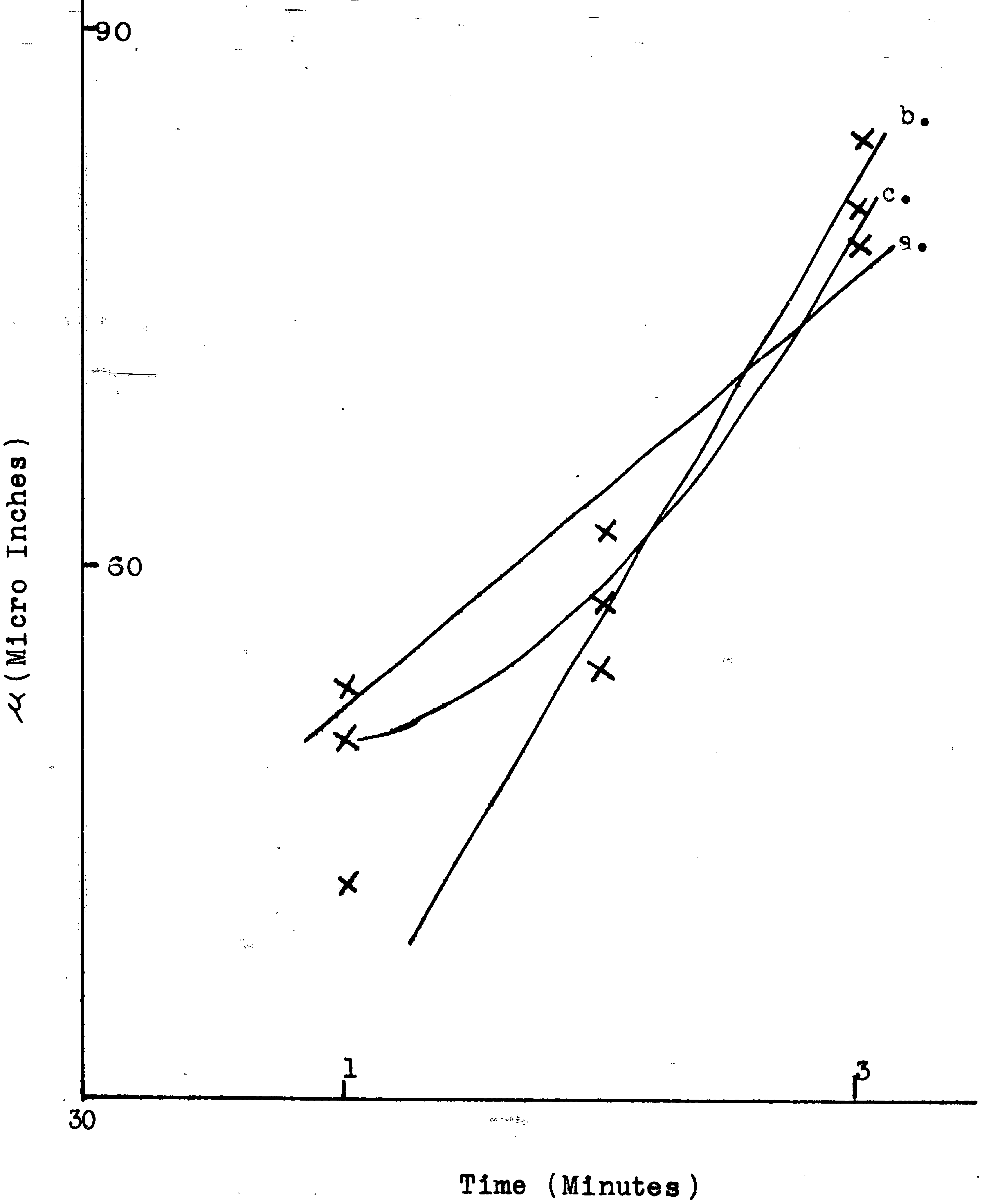
Graph XV. Surface Finish vs. Time

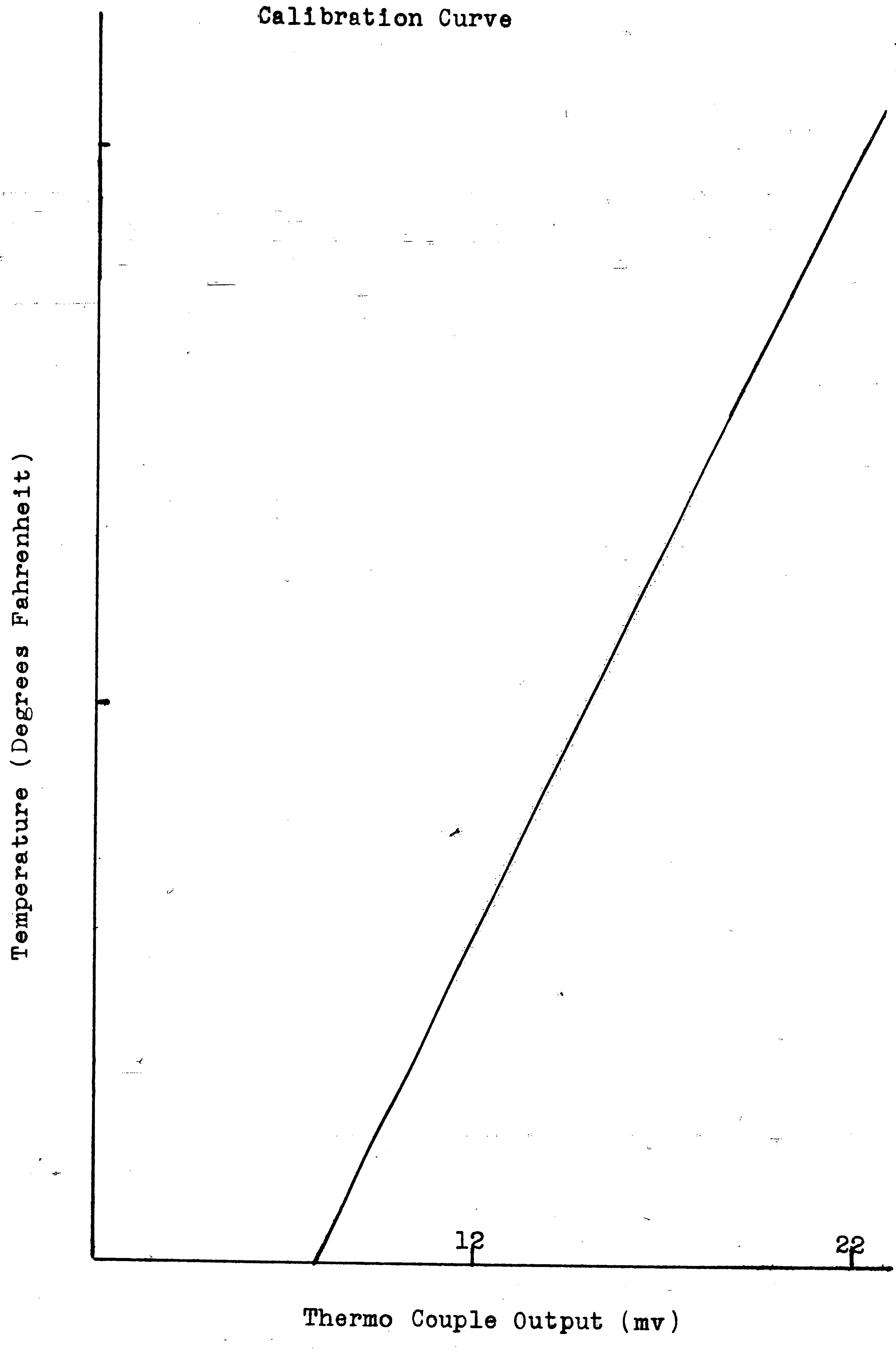
Speed - 700 Surface Feet Per Minute

a. Spray Mist

b. Ambient Air

c. Flood




Calibration Curve
Temperature (Degrees Fahrenheit)
12
22
Thermo Couple Output (mv)

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